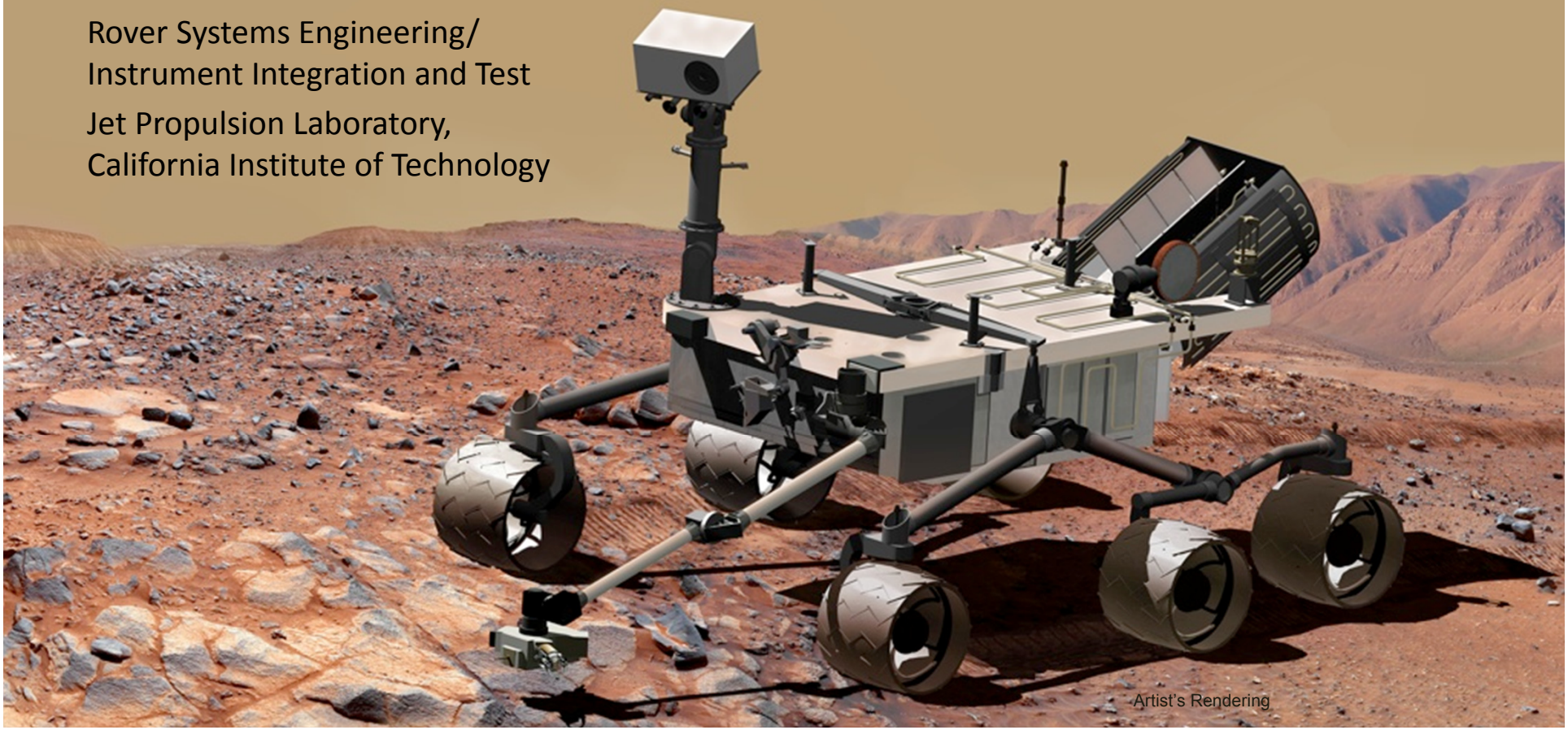
The Mars Science Laboratory "Curiosity" Rover

Betina Pavri

Rover Systems Engineering/
Instrument Integration and Test

Jet Propulsion Laboratory,
California Institute of Technology



Artist's Rendering

NASA's Past, Current and Proposed Mars Exploration Program

Launch Year

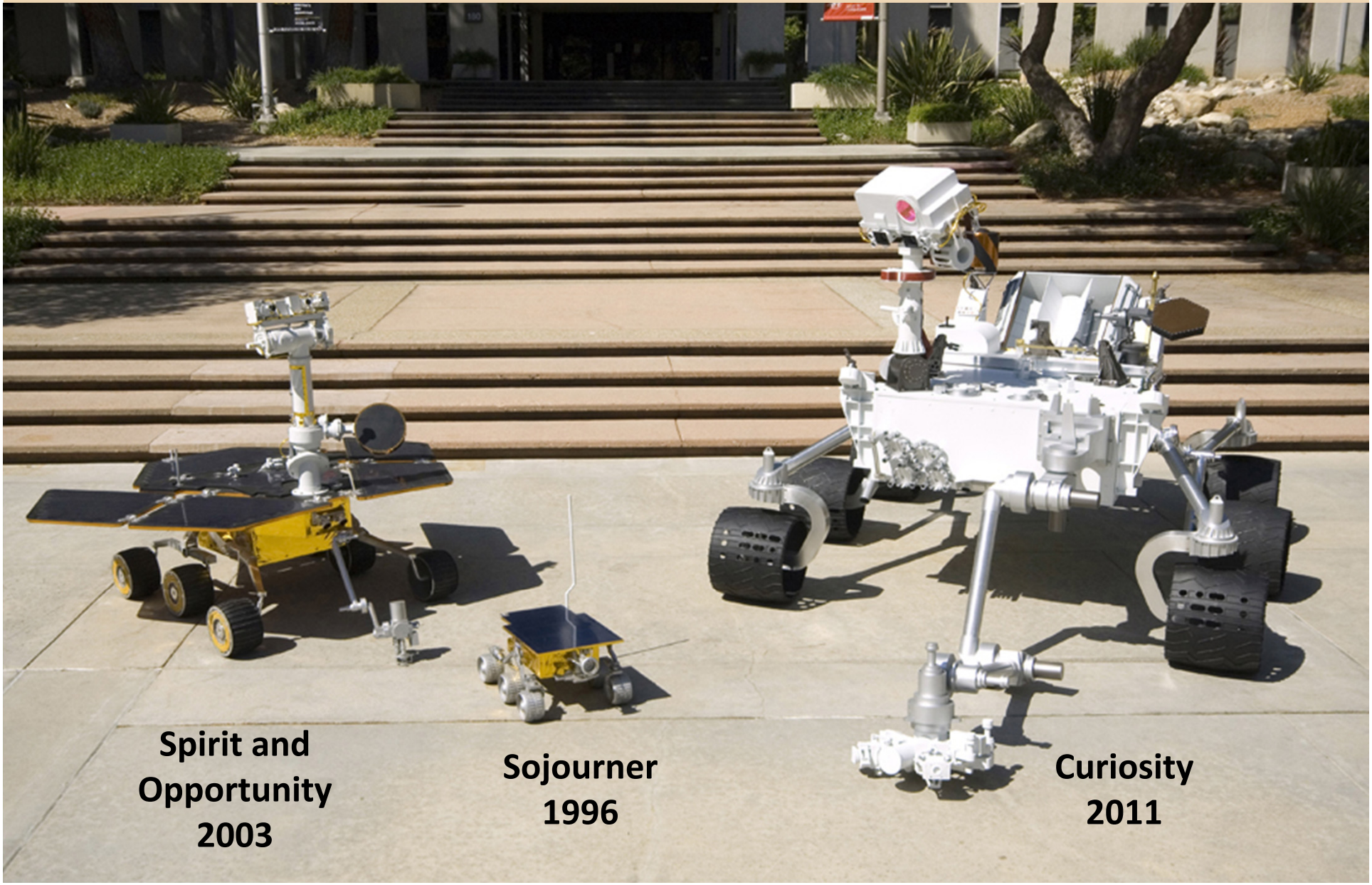
2000 to Present	2011	2013	2016	2018	2020 & Beyond
Odyssey, MRO, Mars Express (ESA)		MAVEN	Proposed TGO (ESA-NASA)		Proposed Mars Sample Return

Recent missions have discovered that Mars' surface reveals a diverse and dynamic history, including evidence for sustained interactions with liquid water.

By studying a potentially habitable, ancient environment, MSL is a bridge to future missions that focus on life detection or returning samples.

MER, MER, Phoenix, Mars Science Lab, Proposed ExoMars, Proposed MAX-C Rover

Rover Family Portrait



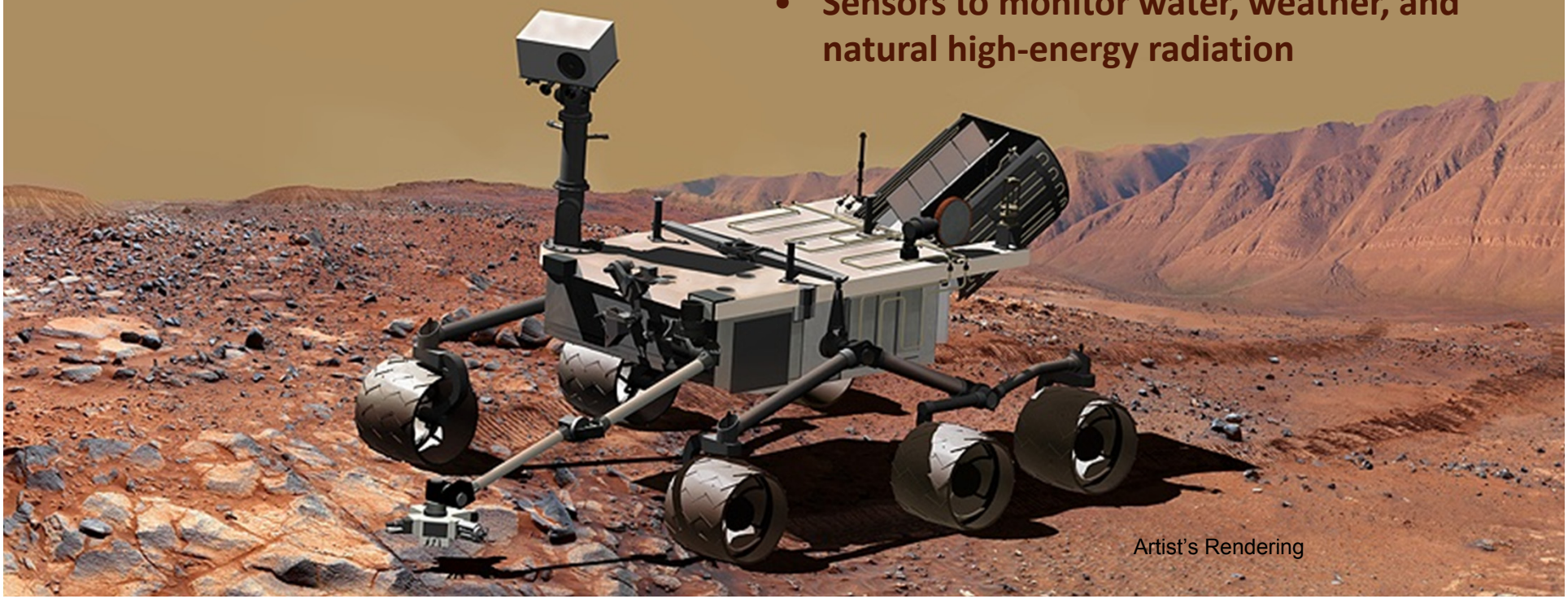
Curiosity's Capabilities

A Robotic Field Geologist

- Long life, ability to traverse many miles over rocky terrain
- Landscape and hand-lens imaging
- Ability to survey composition of bedrock and regolith

A Mobile Geochemical and Environmental Laboratory

- Ability to acquire and process dozens of rock and soil samples
- Instruments that analyze samples for chemistry, mineralogy, and organics
- Sensors to monitor water, weather, and natural high-energy radiation



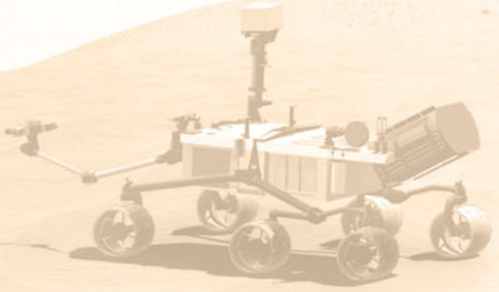
Artist's Rendering

Curiosity's Science Goals

Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

Objectives include:

- Assessing the biological potential of the site by investigating any organic and inorganic compounds and the processes that might preserve them
- Characterizing geology and geochemistry, including chemical, mineralogical, and isotopic composition, and geological processes
- Investigating the role of water, atmospheric evolution, and modern weather/climate
- Characterizing the spectrum of surface radiation

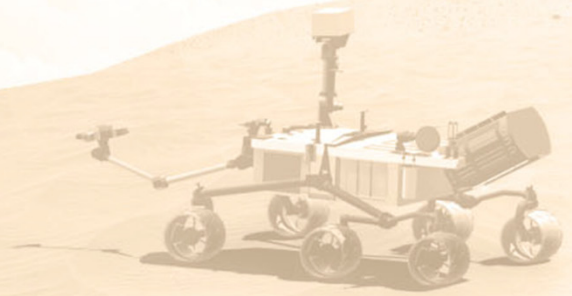


Artist's Rendering

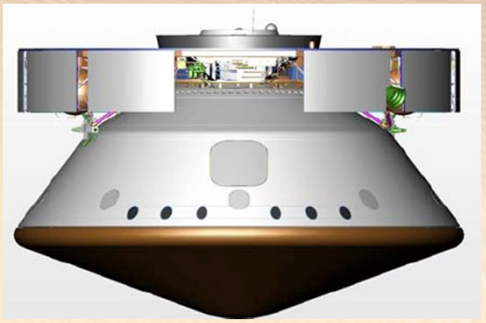
My Role on MSL

- Work with science team to define and verify requirements for science instruments.
- Collaborate with instrument builders and rover team to develop and execute procedures for mechanical and electrical integration with the rover and functional testing of those instruments
- After everything is integrated - What's next?
  - Scenario/Day-in-the-life testing
  - Environmental Testing
    - Vibration
    - Electromagnetic Compatibility
    - Surface & Vacuum Thermal Testing
  - Preparation for Launch
  - Launch/Cruise/EDL
  - Operations on Mars!

Mission and Rover Overview



MSL Mission Overview

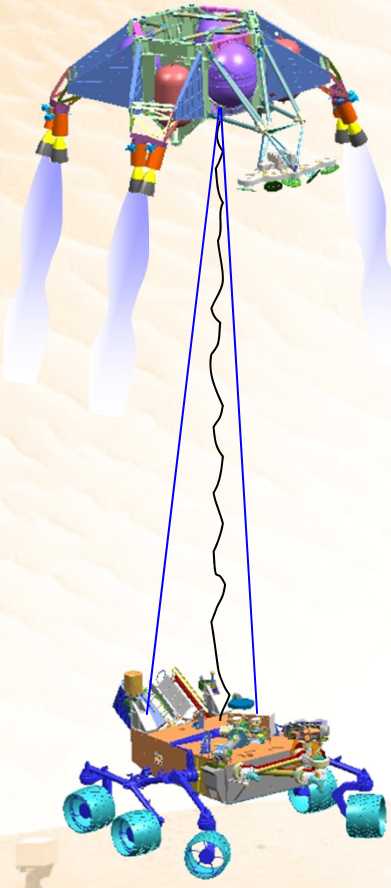


CRUISE/APPROACH

- 8 to 9-month cruise
- Arrive August 6-20, 2012

ENTRY, DESCENT, LANDING

- Guided entry and powered "sky crane" descent
- 20 × 25-km landing ellipse
- Access to landing sites ±30° latitude, <0 km elevation
- 900-kg rover



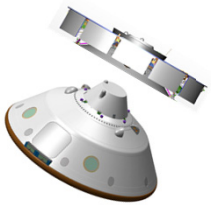
SURFACE MISSION

- Prime mission is one Mars year (687 days)
- Latitude-independent and long-lived power source
- Ability to drive out of landing ellipse
- 72 kg of science payload
- Direct (uplink) and relayed (downlink) communication
- Fast CPU and large data storage

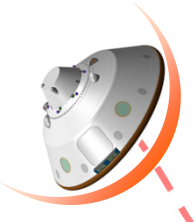
LAUNCH

- Window is Nov. 25 to Dec. 18, 2011
- Atlas V (541)

MSL Entry, Descent, and Landing

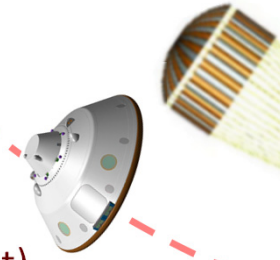


Cruise Stage Separation

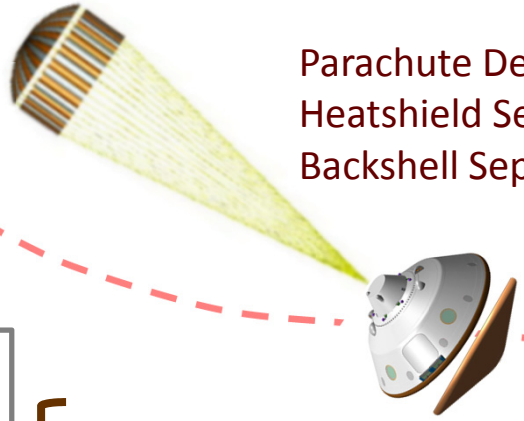


Max Heating and Deceleration

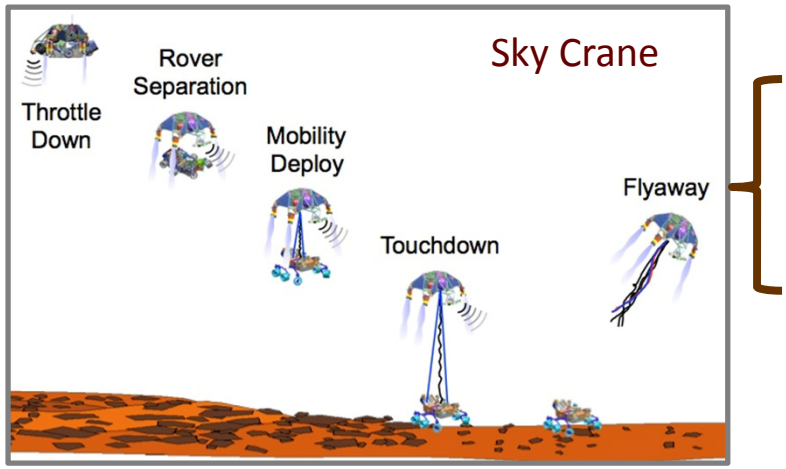
- **Guided entry corrects for atmospheric variability and improves landing accuracy**
- **"Sky Crane" design places the rover directly on Martian soil while keeping the rockets away from the ground**



Guided Entry (horizontal flight)



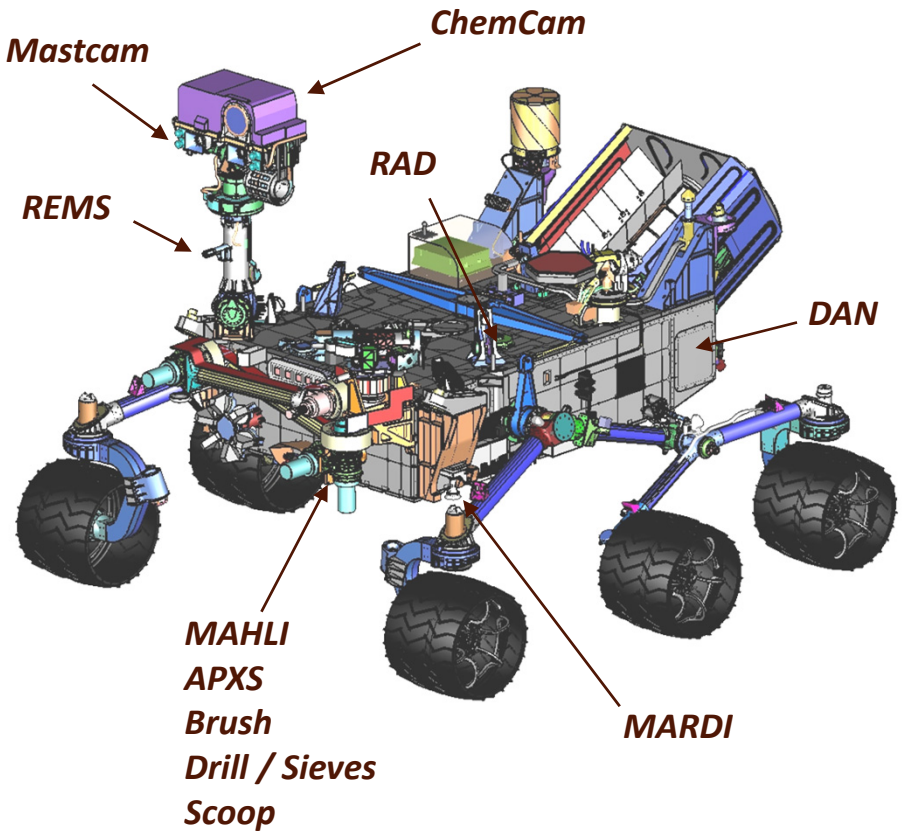
Parachute Descent
Heatshield Separation
Backshell Separation



Powered Descent

Touchdown

MSL Science Payload



Wheel Base:	**2.8 m**
Height of Deck:	**1.1 m**
Ground Clearance:	**0.66 m**
Height of Mast:	**2.2 m**

REMOTE SENSING

Mastcam (M. Malin, MSSS) - Color and telephoto imaging, video, atmospheric opacity

ChemCam (R. Wiens, LANL/CNES) – Chemical composition; remote micro-imaging

CONTACT INSTRUMENTS (ARM)

MAHLI (K. Edgett, MSSS) – Hand-lens color imaging

APXS (R. Gellert, U. Guelph, Canada) - Chemical composition

ANALYTICAL LABORATORY (ROVER BODY)

SAM (P. Mahaffy, GSFC/CNES) - Chemical and isotopic composition, including organics

CheMin (D. Blake, ARC) - Mineralogy

ENVIRONMENTAL CHARACTERIZATION

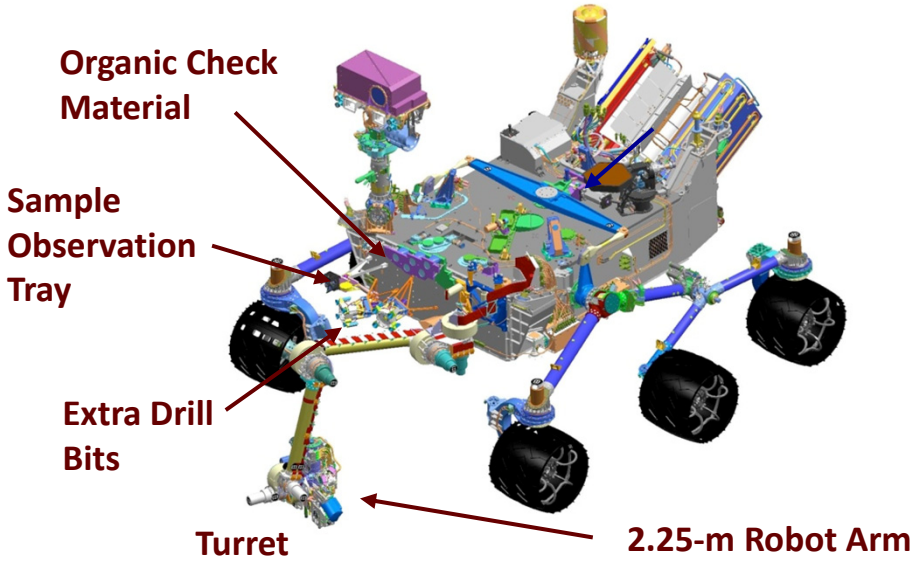
MARDI (M. Malin, MSSS) - Descent imaging

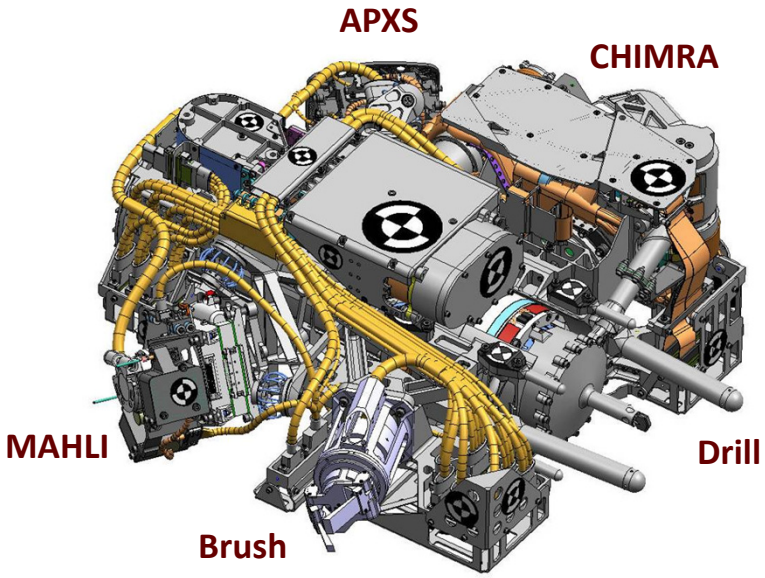
REMS (J. Gómez-Elvira, CAB, Spain) - Meteorology / UV

RAD (D. Hassler, SwRI) - High-energy radiation

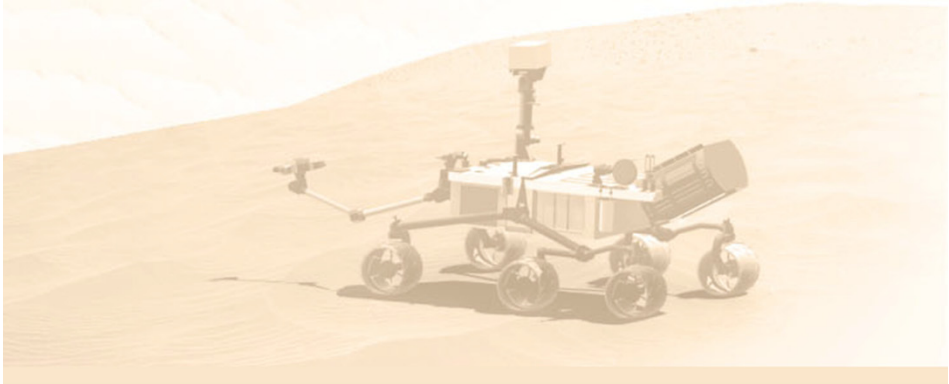
DAN (I. Mitrofanov, IKI, Russia) - Subsurface hydrogen

MSL Sampling System





- Cleans rock surfaces with a brush
- Places and holds the APXS and MAHLI instruments
- Acquires samples of rock or soil with a powdering drill or scoop
- Sieves the samples (to 150 µm or 1 mm) and delivers them to instruments or an observation tray
- Exchanges spare drill bits



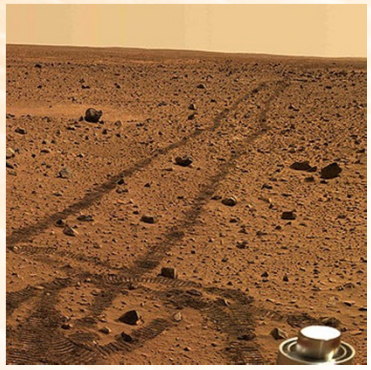
MSL Science Operations

1. REMOTE SENSING

- Landscape imaging
- Sampling of rock and soil chemistry

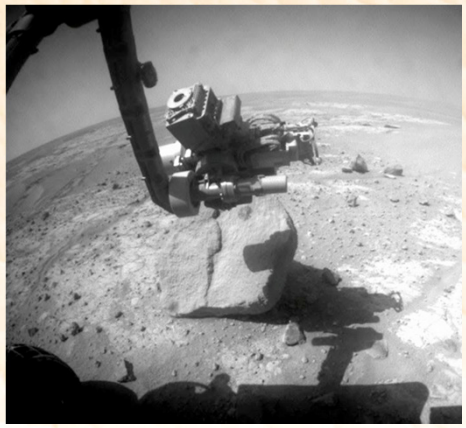
2. TRAVERSE/APPROACH

- Driving up to 100 m per sol
- Imaging and profiling chemistry along the drive
- Locating sampling targets



3. CONTACT SCIENCE

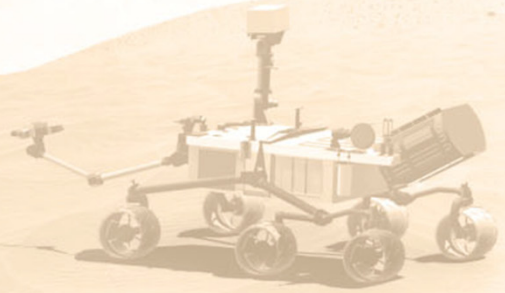
- Removal of surface dust
- Chemical and hand-lens observations of a specific target



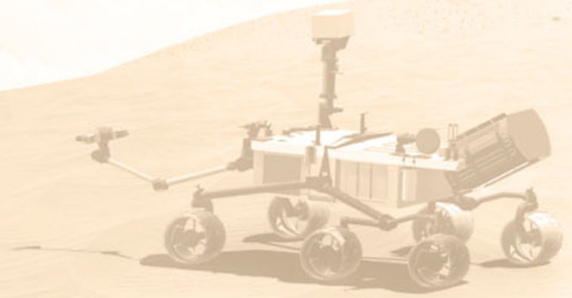
4. SAMPLE ACQUISITION/ANALYSIS

- Drilling, processing, and delivering sample material to the rover's lab instruments
- Analyzing for mineralogy, organics, elemental and isotopic chemistry

Each activity may require multiple sols. Results are reviewed on Earth before moving on to the next activity. Weather and radiation monitoring occur on all sols.



MSL Science Investigations

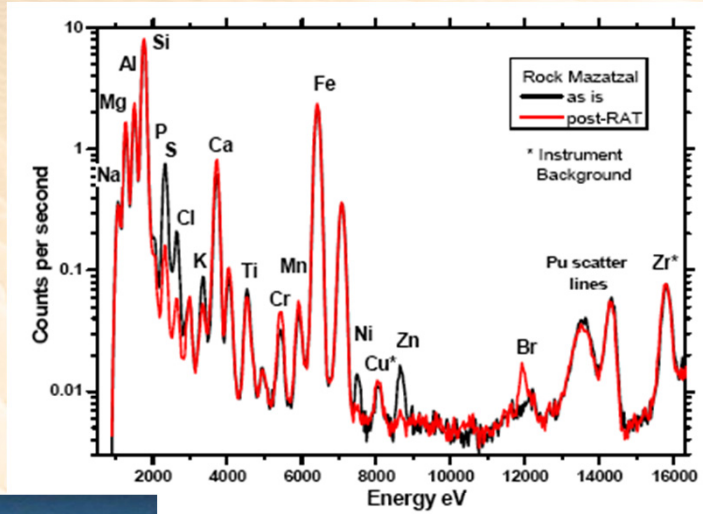


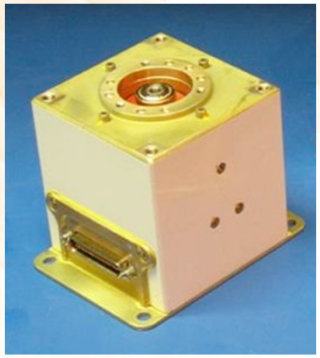
Alpha-Particle X-ray Spectrometer

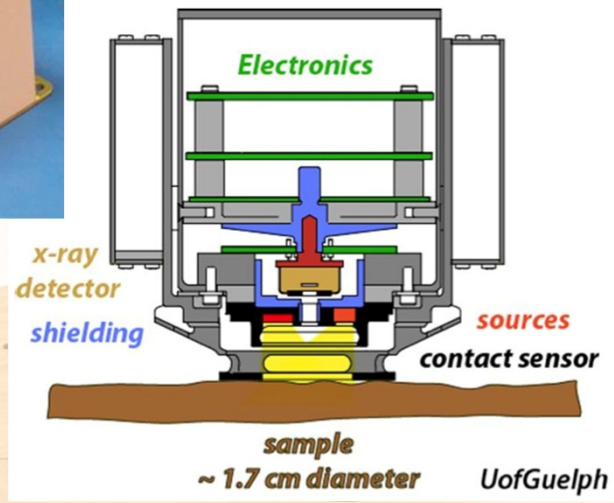
Principal Investigator: Ralf Gellert
University of Guelph, Ontario, Canada
Canadian Space Agency

APXS determines the chemical composition of rocks, soils, and processed samples

- Combination of particle-induced X-ray emission and X -ray fluorescence using ^{244}Cm sources
- Rock-forming elements from Na to Br and beyond
- Useful for lateral / vertical variability, surface alteration, detection of salt-forming elements
- Factor of ~3 increased sensitivity; better daytime performance compared with MER







ChemCam

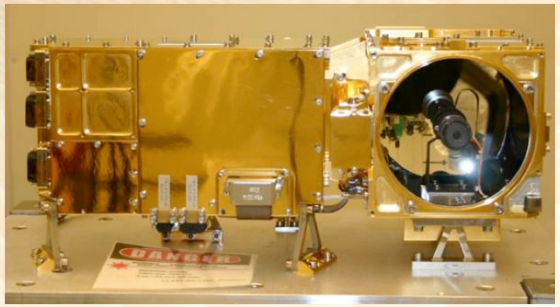
Principal Investigator: Roger Wiens

Los Alamos National Laboratory

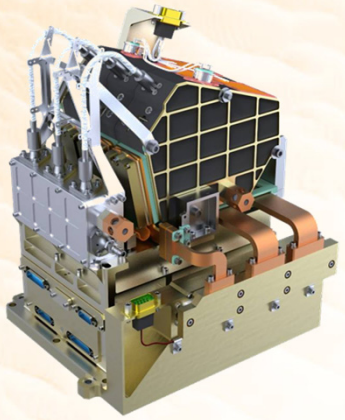
L'Institut de Recherche en Astro. et Planétologies

ChemCam performs elemental analyses through laser-induced breakdown spectroscopy (LIBS)

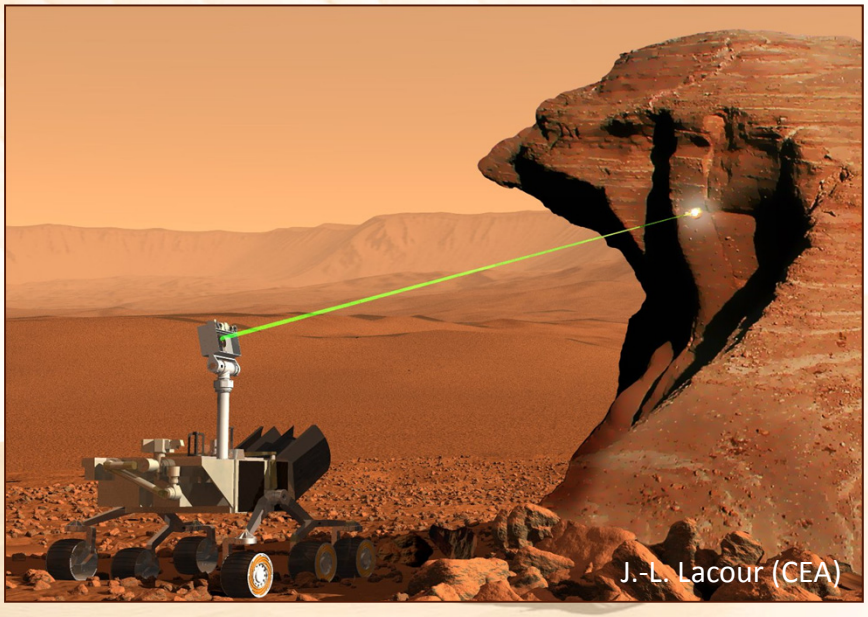
- Rapid characterization of rocks and soils up to seven meters away
- Will identify and classify rocks, soils, pebbles, hydrated minerals, weathering layers, and ices
- Analysis spot size < 0.5 mm
- 240-850 nm spectral range
- Dust removal; depth profiling to > 0.5 mm
- High-resolution context imaging (resolves ~1 mm at 10 m)



Mast Unit



Body Unit



Artist's Rendering

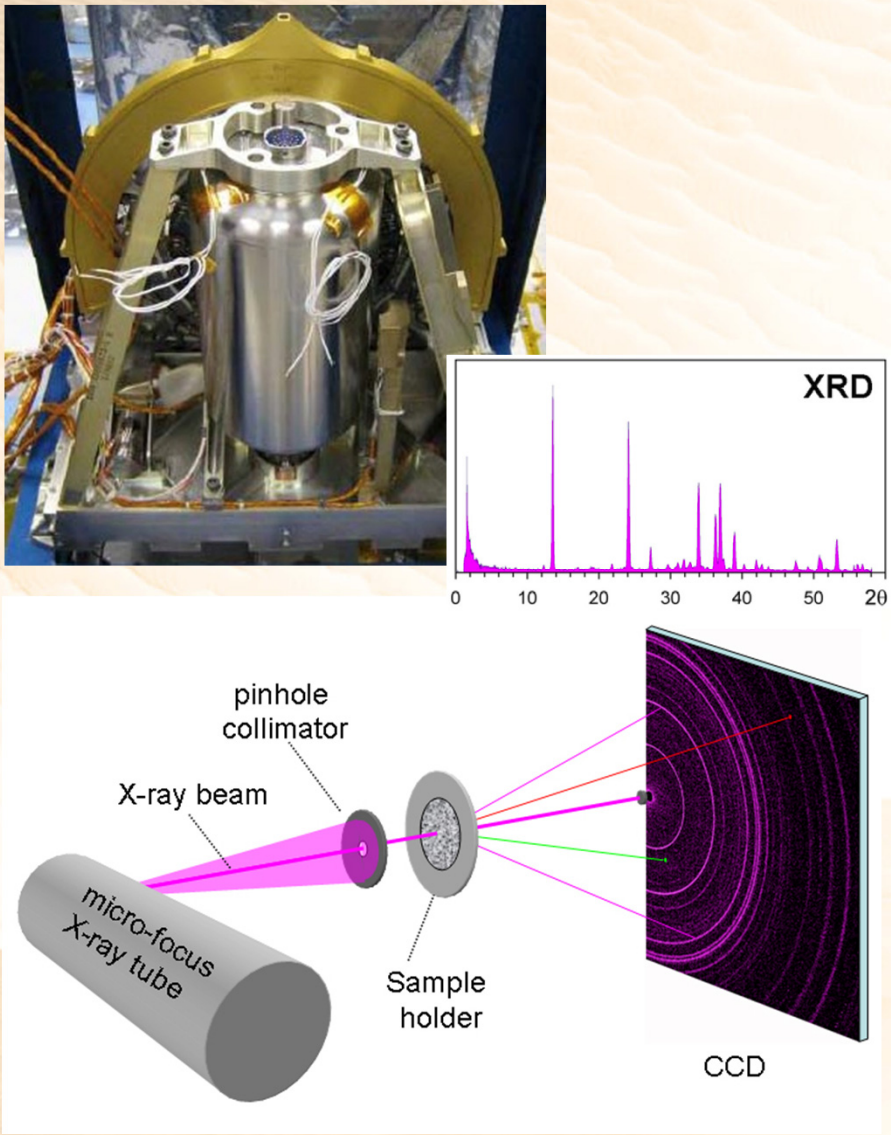
Chemistry and Mineralogy (CheMin)

Principal Investigator: David Blake

NASA Ames Research Center

CheMin derives definitive mineralogy

- X-ray diffraction (XRD); standard technique for laboratory analysis
- Identification and quantification of minerals in geologic materials (e.g., basalts, evaporites, soils)
- Will assess role of water in formation, deposition, alteration
- Accuracy of ±15% in concentration for major mineral components



Dynamic Albedo of Neutrons (DAN)

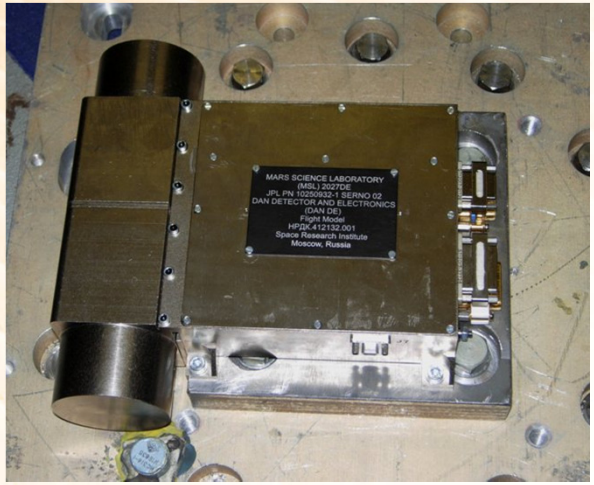
Principal Investigator: Igor Mitrofanov

Space Research Institute (IKI), Russia

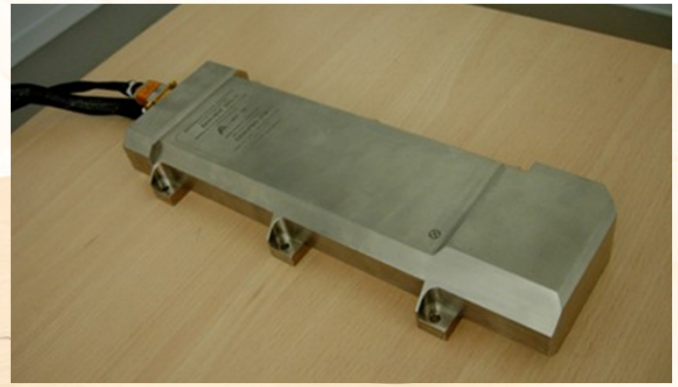
DAN measures the abundance of H and OH bearing materials (e.g., adsorbed water or hydrated minerals)

- Active neutron spectroscopy with pulsed 14 MeV neutrons or passive
- Creates profiles along traverses and with depth to 1 m
- Resolves time decay curve and energy spectrum of returned pulse
- Accuracy of 0.1-1% by weight of water (or water-equivalent hydrogen) depending on observation type

Thermal & Epithermal Neutron Detectors



Pulsing Neutron Generator



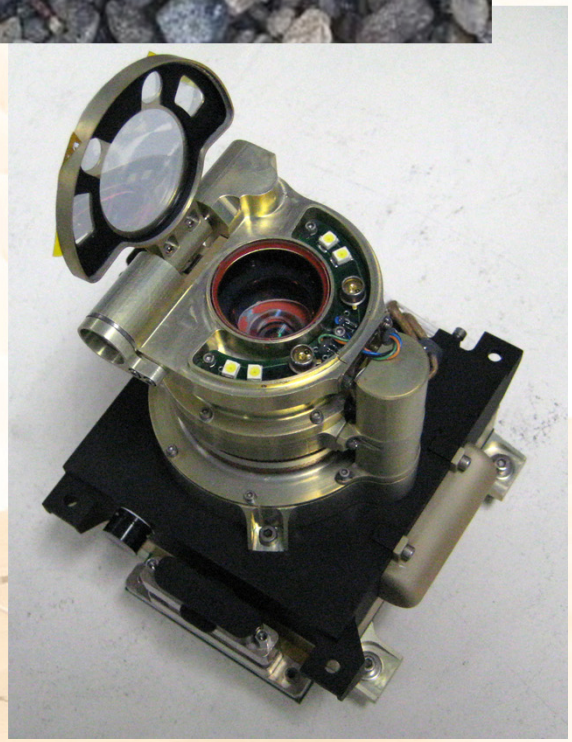
Mars Hand-Lens Imager (MAHLI)

Principal Investigator: Ken Edgett

Malin Space Science Systems

MAHLI characterizes the history and processes recorded in geologic materials

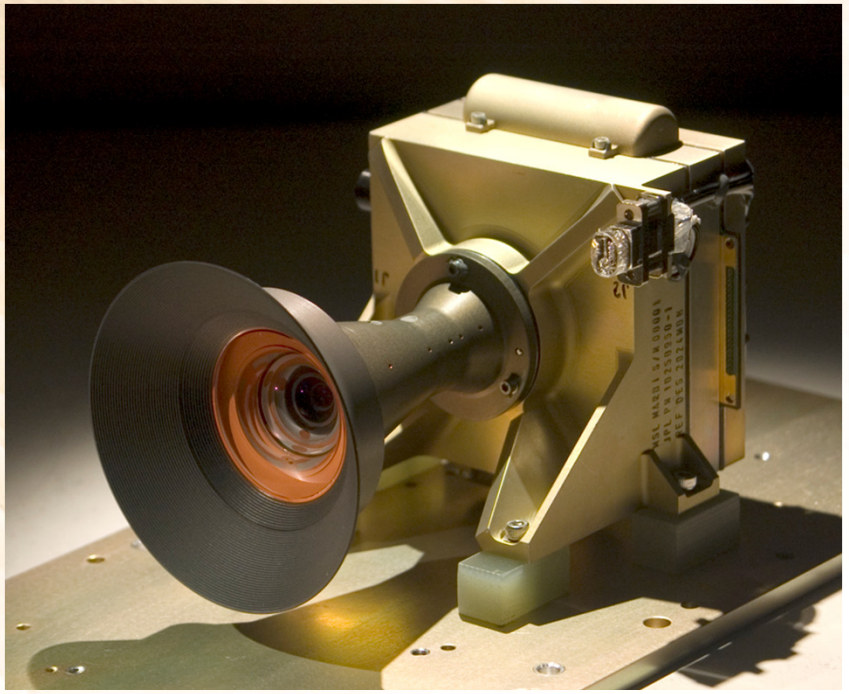
- Examines the structure and texture of rocks, fines, and frost/ice at micron to cm scale
- Returns 1600 × 1200-pixel color images and video; synthesizes best-focus images and depth-of-field range maps
- Highest possible spatial resolution is 14 μm/pixel
- Can focus at distances suitable for landscape and engineering support/diagnostic imaging
- White light and UV LEDs for controlled illumination, fluorescence



Mars Descent Imager (MARDI)

Principal Investigator: Michael Malin

Malin Space Science Systems



MARDI provides detailed imagery of the MSL landing region

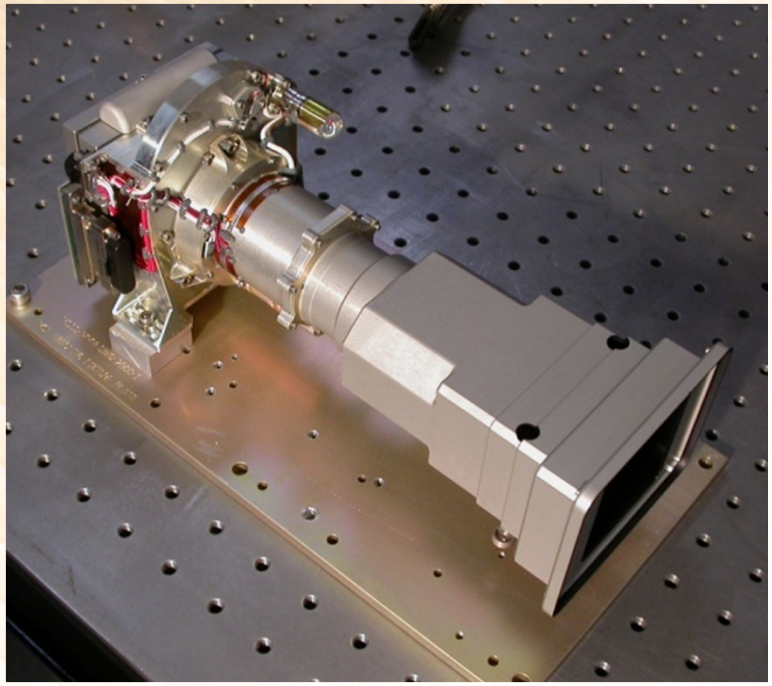
- Acquires images during powered descent ranging from 1.5 m/pixel to 1 mm/pixel at the surface. Ties post-landing surface images to pre-landing orbital images.
- Bayer pattern filter for natural color
- High-definition, video-like data acquisition (1600×1200 pixels, 4.5 frames per second)
- Large internal storage: 256 MByte SRAM, 8 GByte flash

Mast Camera (Mastcam)

Principal Investigator: Michael Malin

Malin Space Science Systems

Mastcam provides color and stereo imaging of the landscape, rocks, fines, frost/ice, and atmospheric features



- Narrow-angle (5.1° FOV) and medium-angle (15° FOV) cameras
- Bayer pattern filter design for natural color plus narrow-band filters for scientific color
- High spatial resolution: 1200×1200 pixels (0.2 mm/pixel at 2 m, 8 cm/pixel at 1 km)
- High-definition video at 5 frames/second, 1280×720 pixels
- Large internal storage: 256 MByte SRAM, 8 GByte flash

Sample Analysis at Mars (SAM)

Principal Investigator: Paul Mahaffy

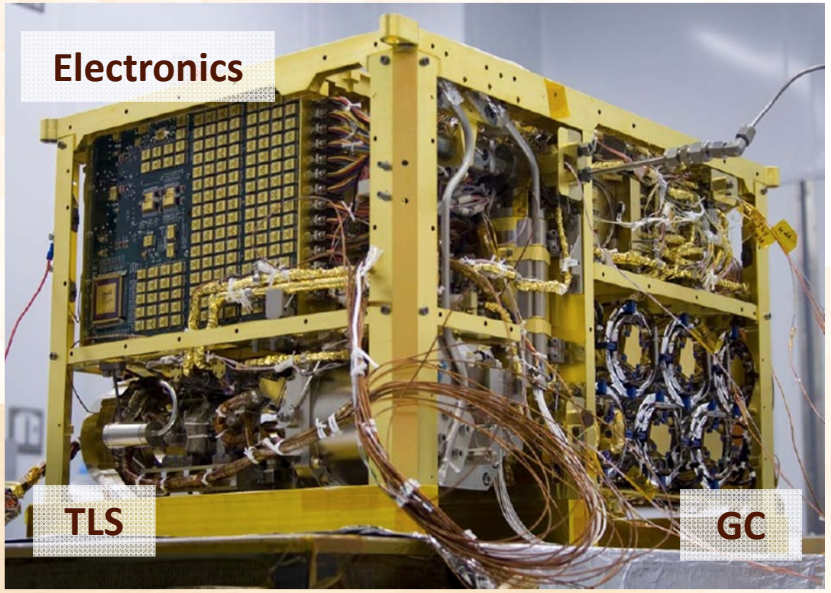
NASA Goddard Space Flight Center

SAM Suite Instruments

Quadrupole Mass Spectrometer (QMS)
Gas Chromatograph (GC)
Tunable Laser Spectrometer (TLS)

- Explore sources and destruction paths for carbon compounds, and search for organic compounds of biotic and prebiotic relevance
- Reveal chemical and isotopic state of other light elements that are important for life as we know it on Earth
- Study atmospheric/surface interactions expressed in trace species compositions
- Investigate atmospheric and climate evolution through isotope measurements of noble gases and light elements

- **QMS:** molecular and isotopic composition in the 2-535 Dalton mass range for atmospheric and evolved gas samples
- **GC:** resolves complex mixtures of organics into separate components
- **TLS:** abundance and isotopic composition of CH_4, CO_2, and H_2O



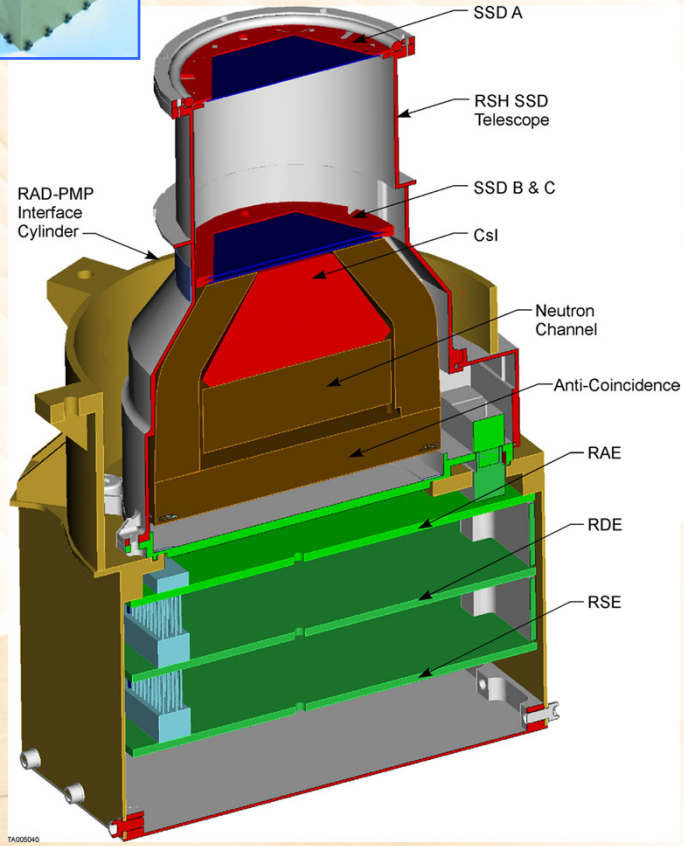
Radiation Assessment Detector (RAD)

Principal Investigator: Donald M. Hassler

Southwest Research Institute

RAD characterizes the radiation environment on the surface of Mars

- Measures galactic cosmic ray and solar energetic particle radiation, including secondary neutrons and other particles created in the atmosphere and regolith
- Determines human dose rate, validates transmission/transport codes, assesses hazard to life, studies the chemical and isotopic effects on Mars' surface and atmosphere
- Solid state detector telescope and CsI calorimeter. Zenith pointed with 65° FOV
- Detects energetic charged particles (Z=1-26), neutrons, gamma rays, and electrons

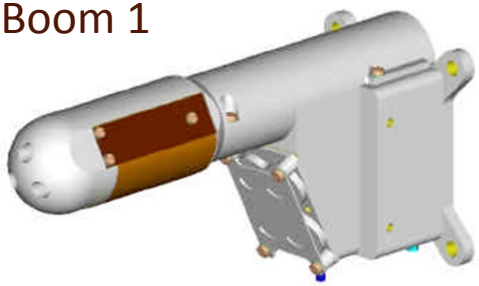


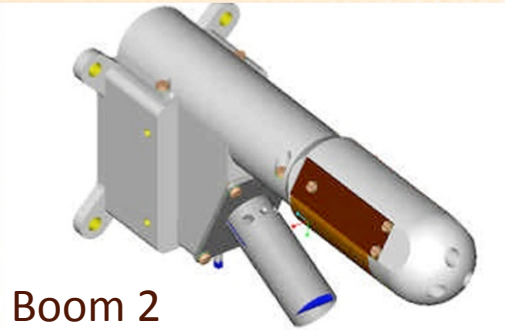
Rover Environmental Monitoring Station (REMS)

Principal Investigator: Javier Gómez-Elvira

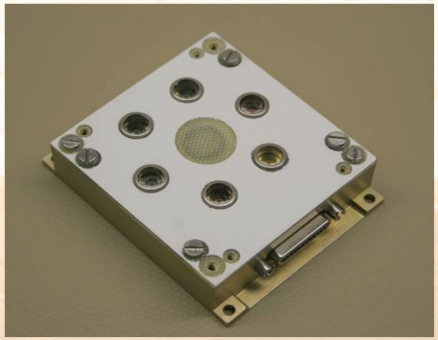
Centro de Astrobiología (CAB), Spain

Boom 1





Boom 2

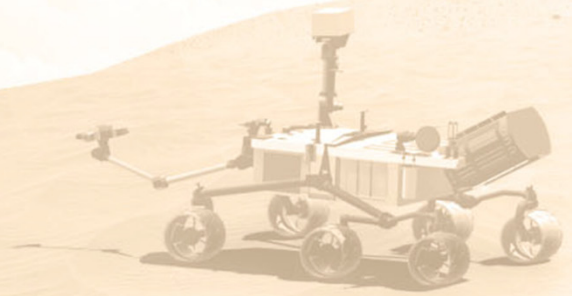


UV Sensor

REMS measures the meteorological and UV radiation environments

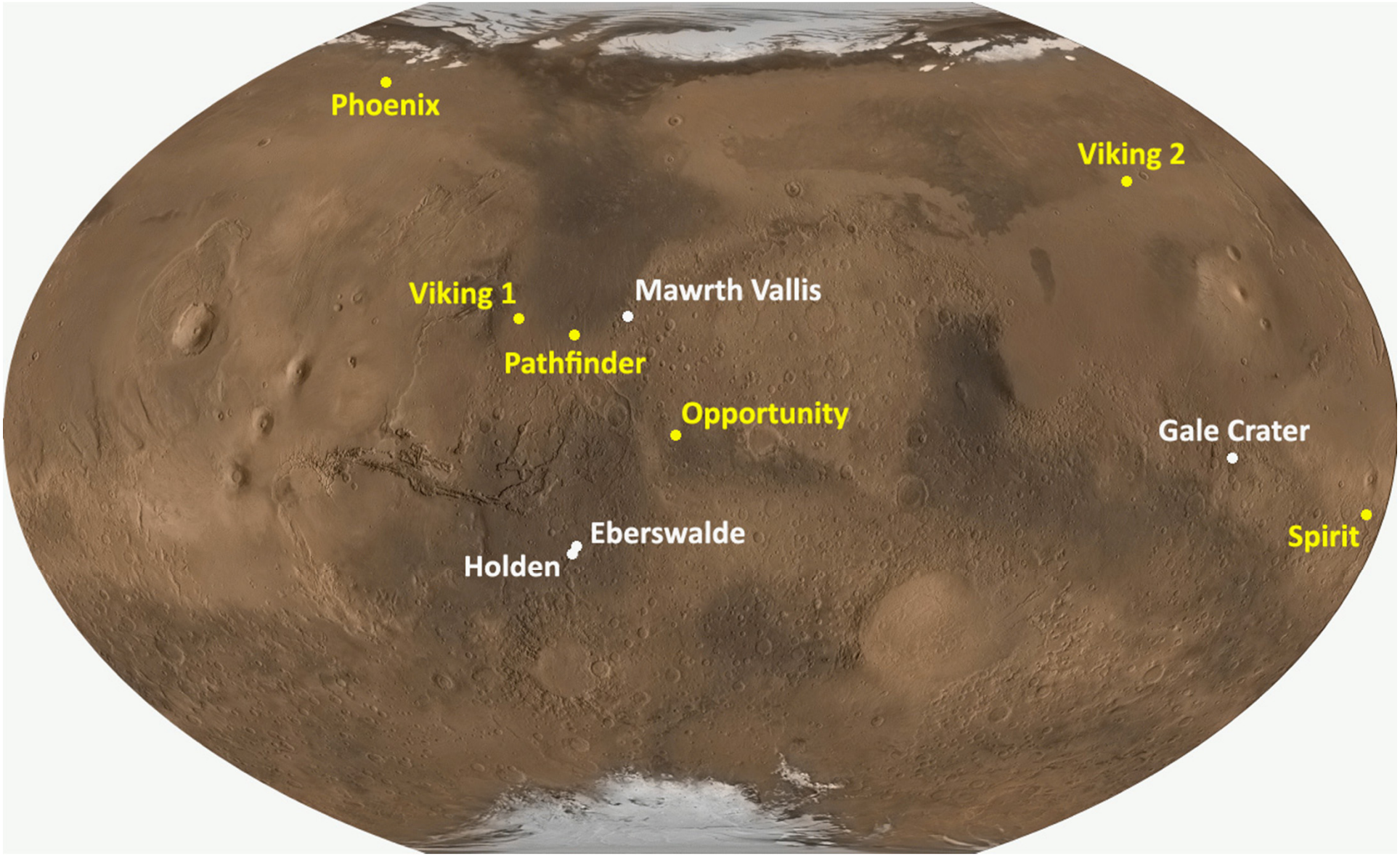
- Two 3-D wind sensors
- Air temperature sensors
- IR ground temperature sensors
- Pressure sensor
- Relative humidity sensor
- UV radiation detector (200 to 400 nm)
- 1-Hz sampling for 5 minutes each hour

Candidate Landing Sites

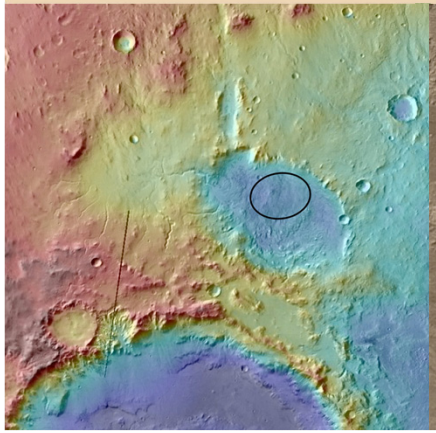
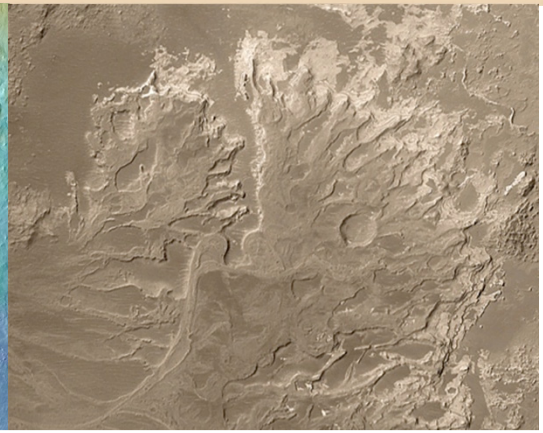


Mars Landing Sites

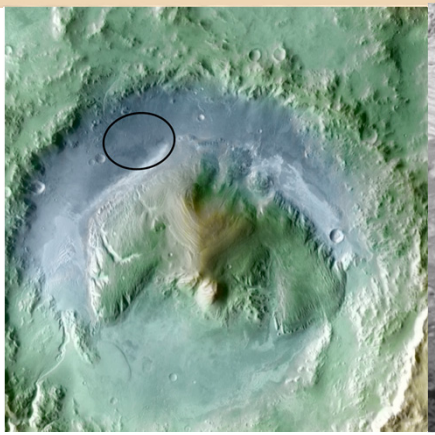
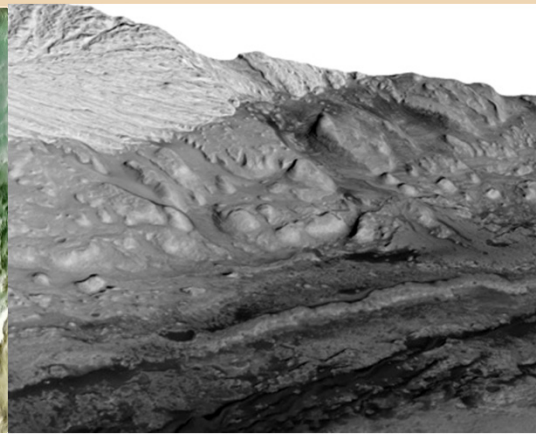
(Previous Missions and MSL Candidates)



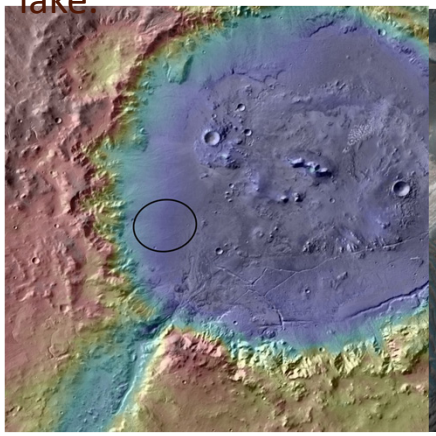
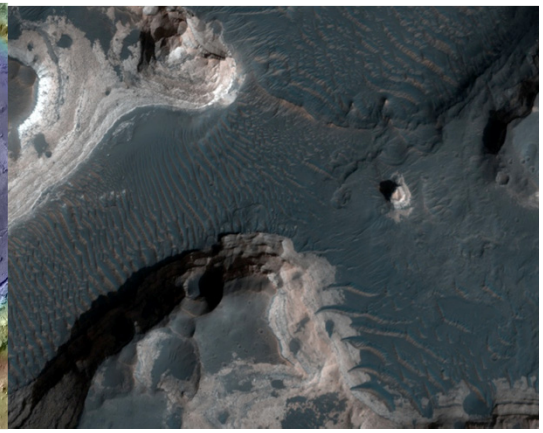
Candidate Landing Sites

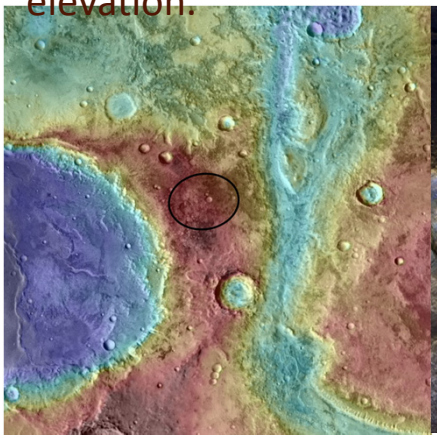
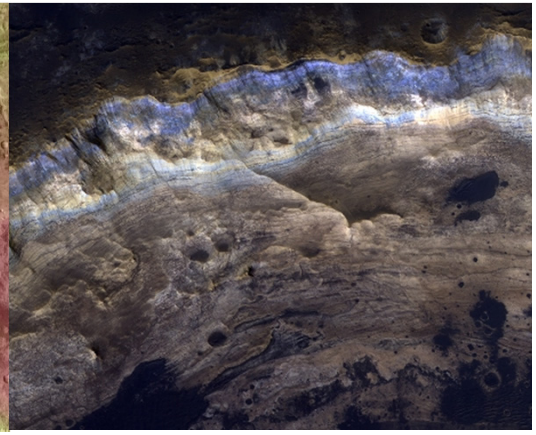
Eberswalde Crater (24° S, 327° E, -1.5 km) contains a clay-bearing delta formed when an ancient river deposited sediment, possibly into a lake.

Gale Crater (4.5° S, 137° E, -4.5 km) contains a 5-km sequence of layers that vary from clay-rich materials near the bottom to sulfates at higher elevation.

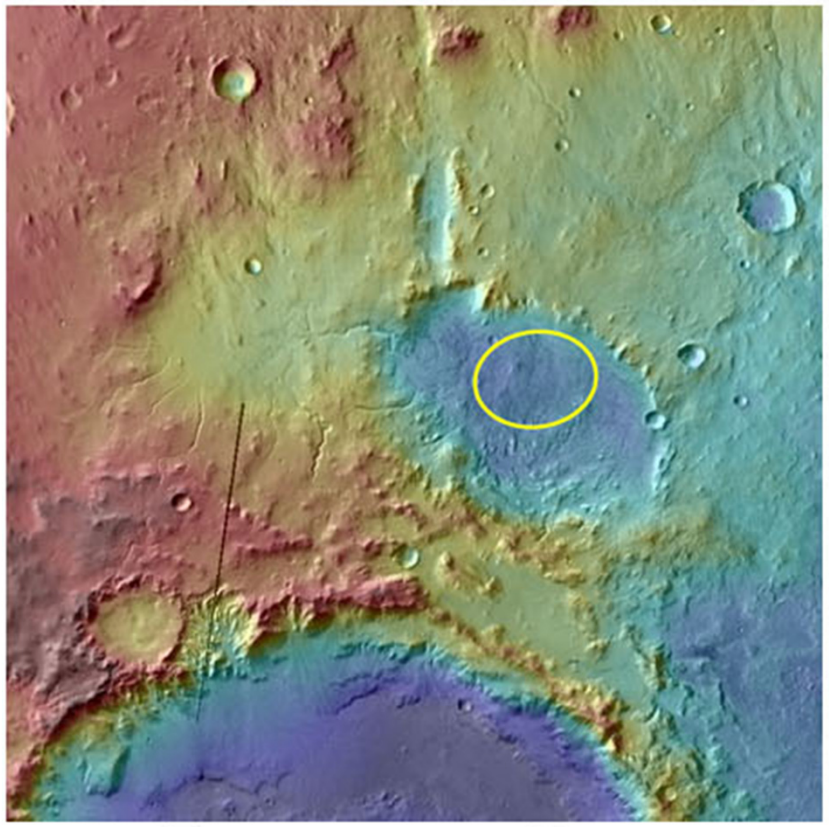
Holden Crater (26° S, 325° E, -1.9 km) has alluvial fans, flood deposits, possible lake beds, and clay-rich sediment.

Mawrth Vallis (24° N, 341° E, -2.2 km) exposes layers within Mars' surface with differing mineralogy, including at least two kinds of clays.

Eberswalde Delta:

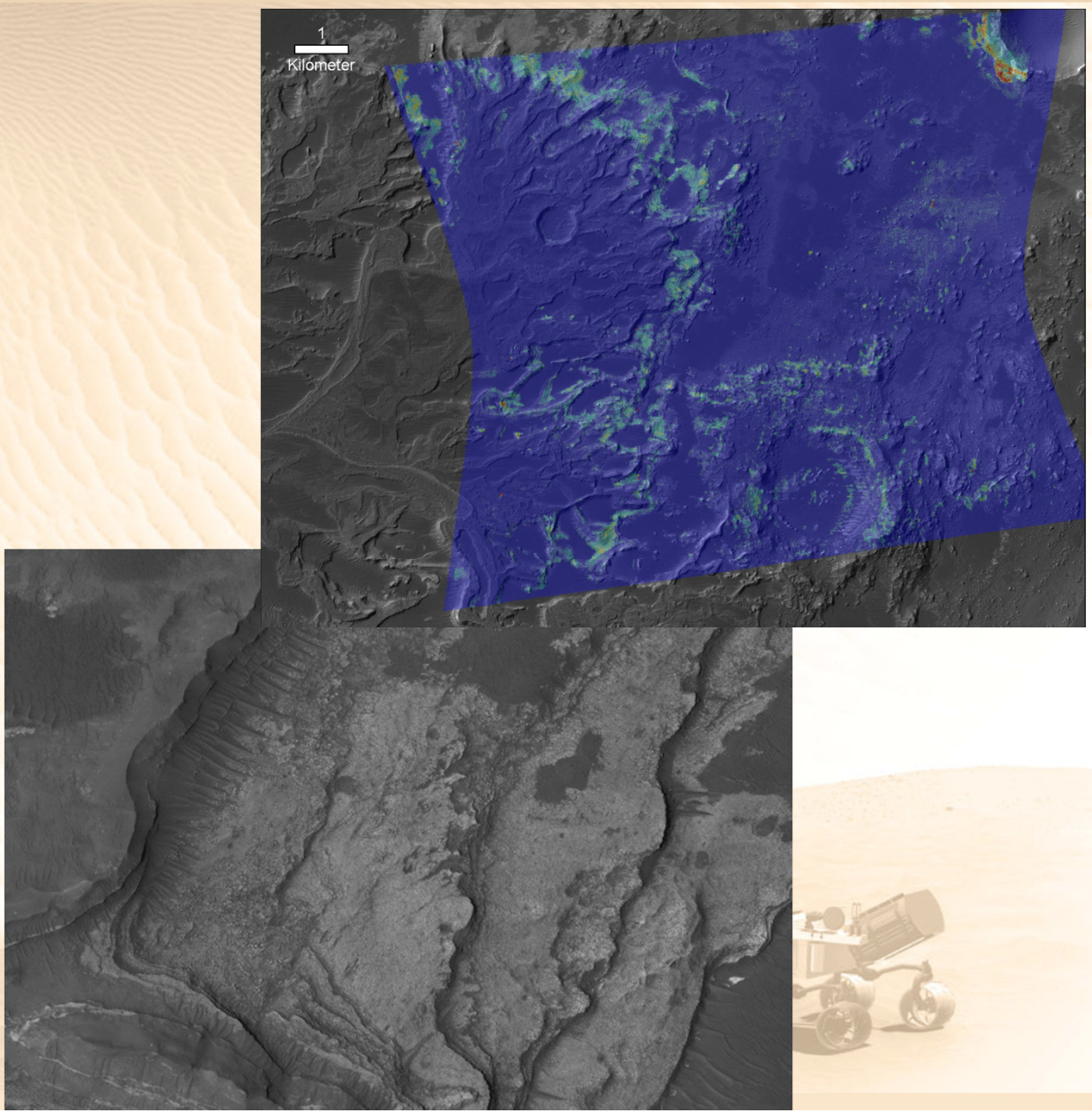
Clay-Bearing Deltaic and Paleolake Deposits along a Major Martian Drainage



EBERSWALDE DELTA
(24S, 327E)

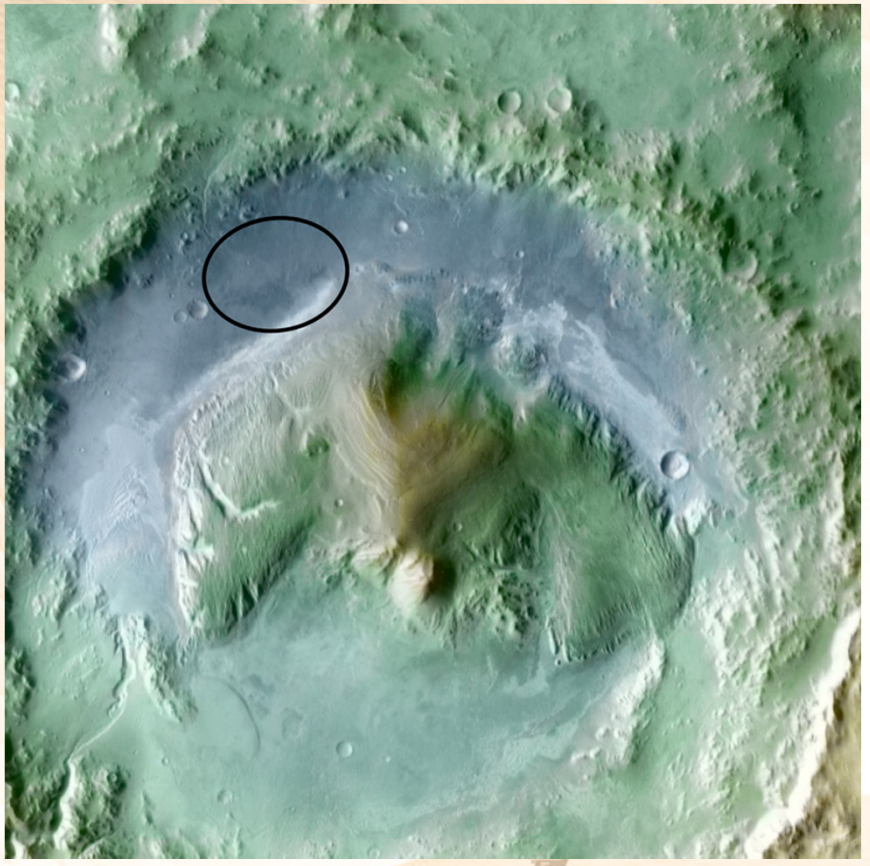
Eberswalde Delta

- *Best evidence for a delta anywhere on Mars*
- *Lighter-toned layers have phyllosilicate signatures in CRISM observations*
- *Evidence for a much larger, paleodeltaic complex exists across all the crater floor, including the ellipse location to the east.*
- *HiRISE images (bottom) show layers exposed at the margin of the deposit.*

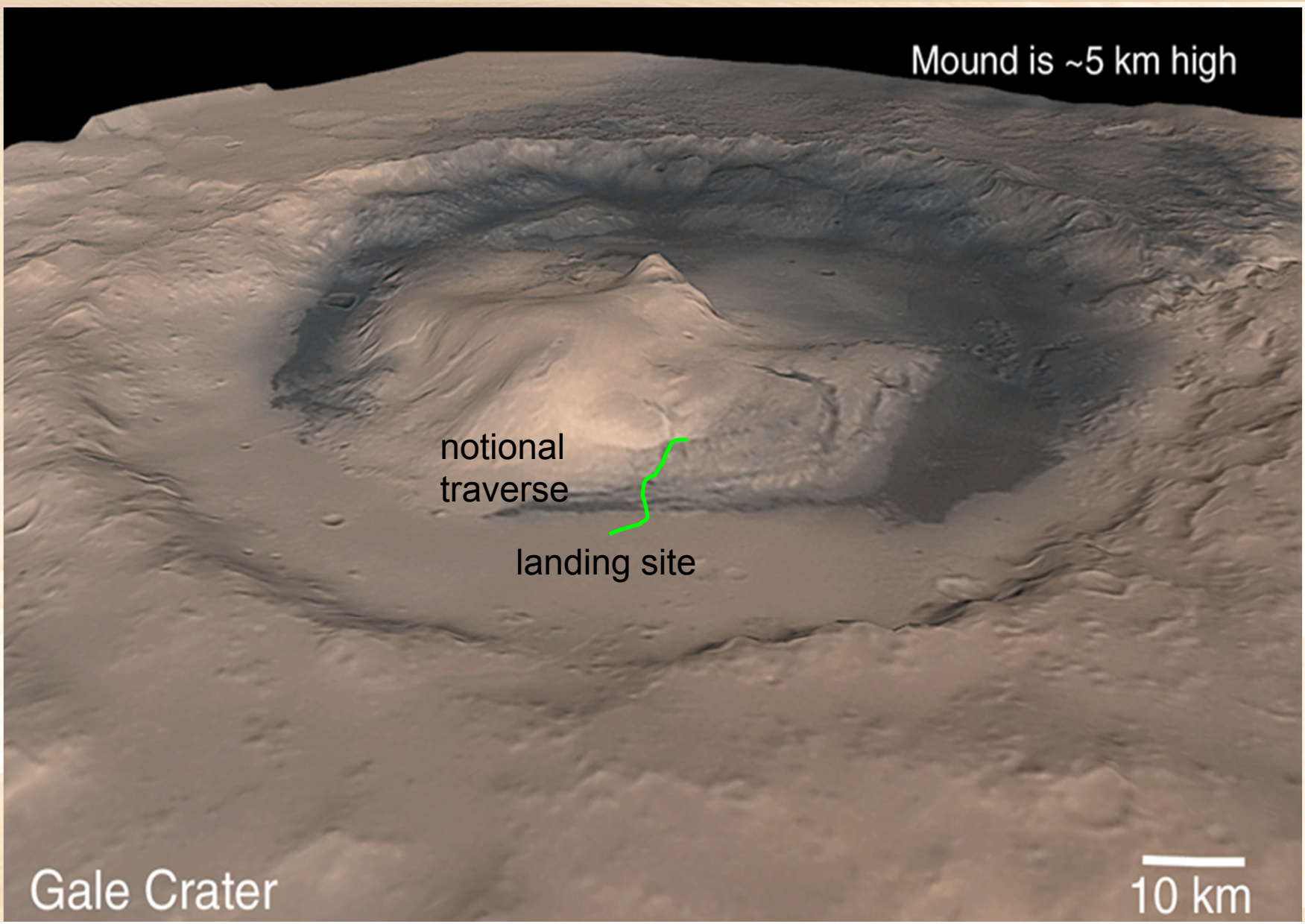


Gale Crater:

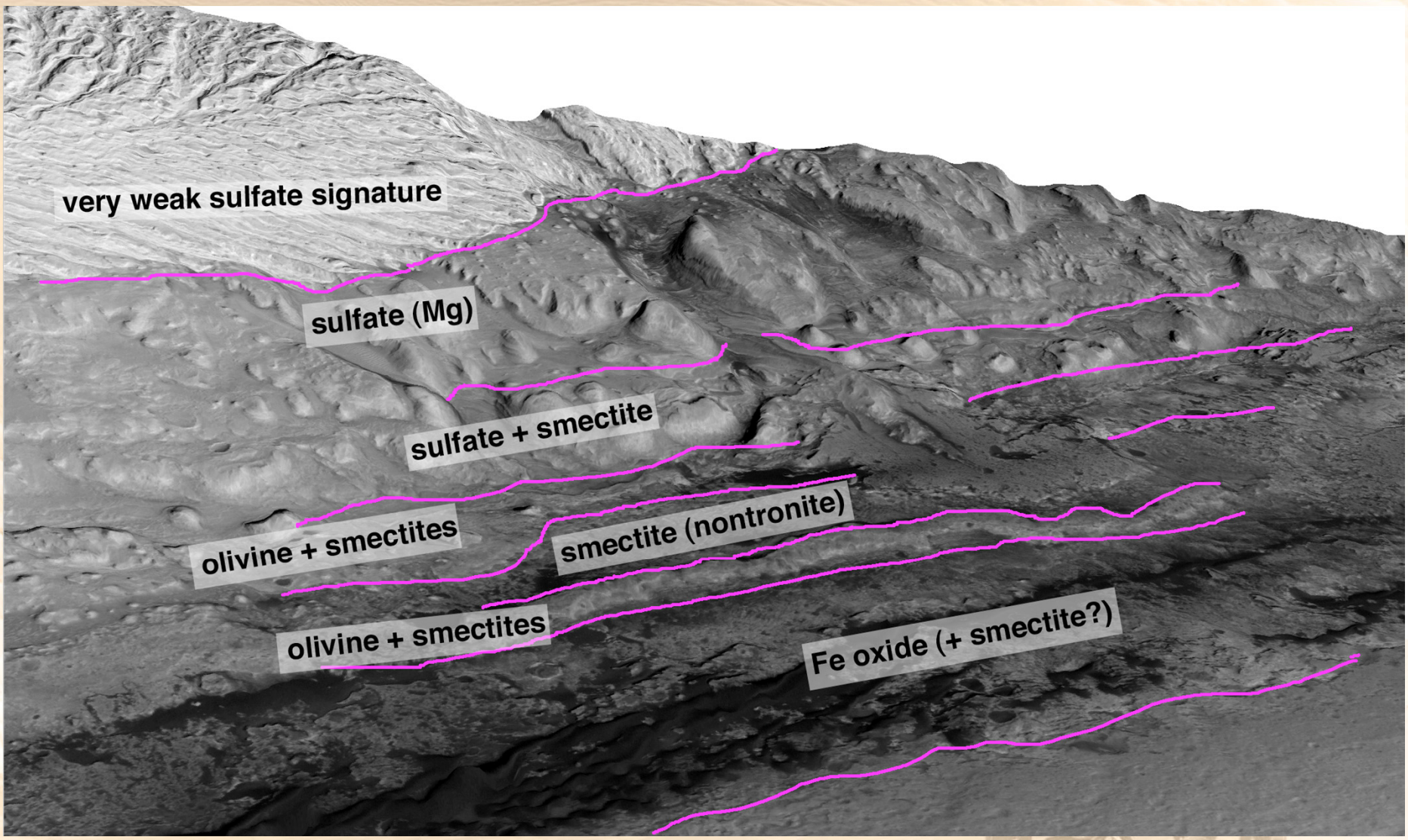
A 5-km Sequence of Layered Materials Recording Major Compositional Changes



Gale Crater


Mound is ~5 km high
notional
traverse
landing site
Gale Crater
10 km

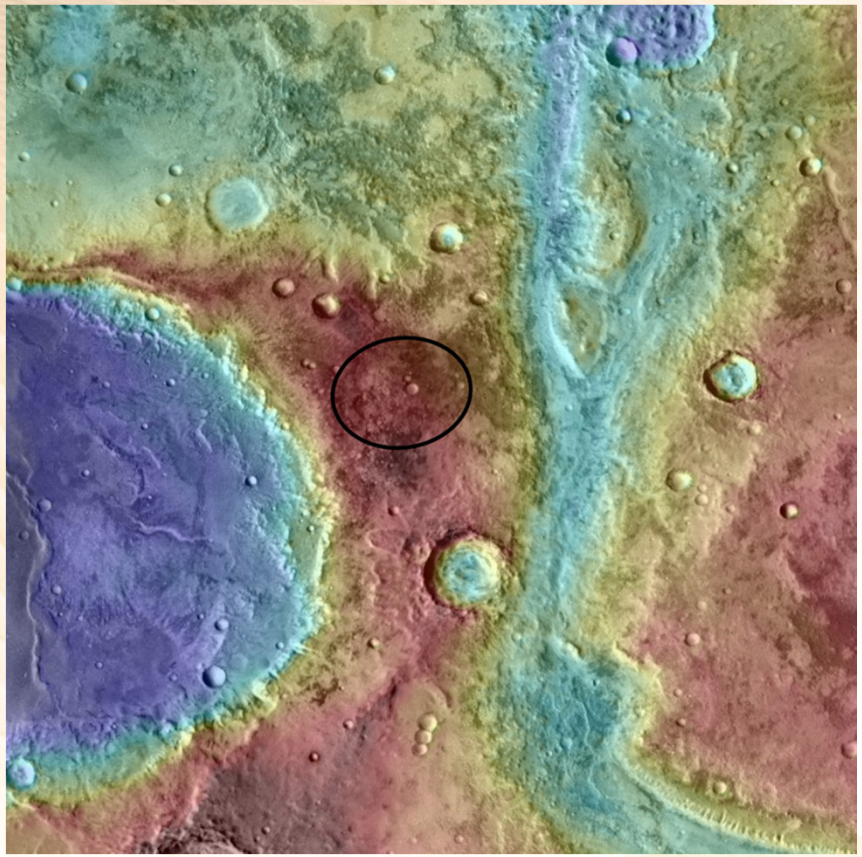
Gale Crater



CTX image overlain on DEM by Larry Edwards from CTX stereo pairs, looking toward southwest.

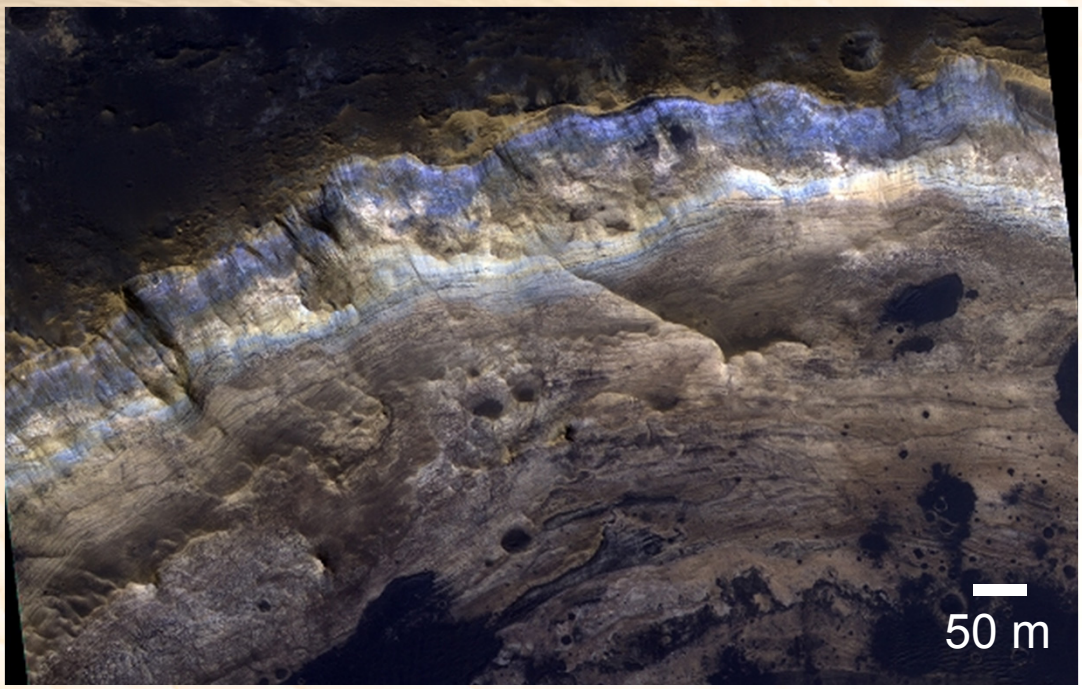
Mawrth Vallis:

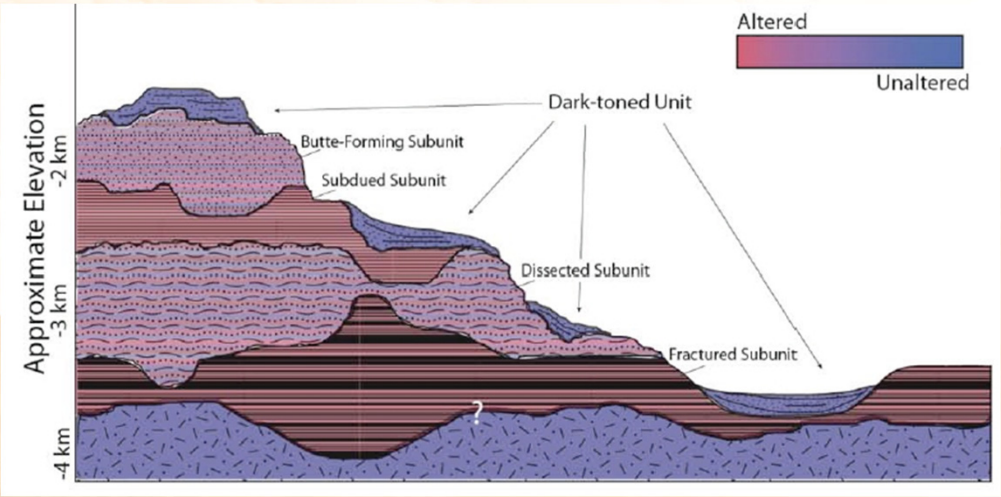
Ancient Phyllosilicate-Bearing Layered Materials near an Outflow Channel

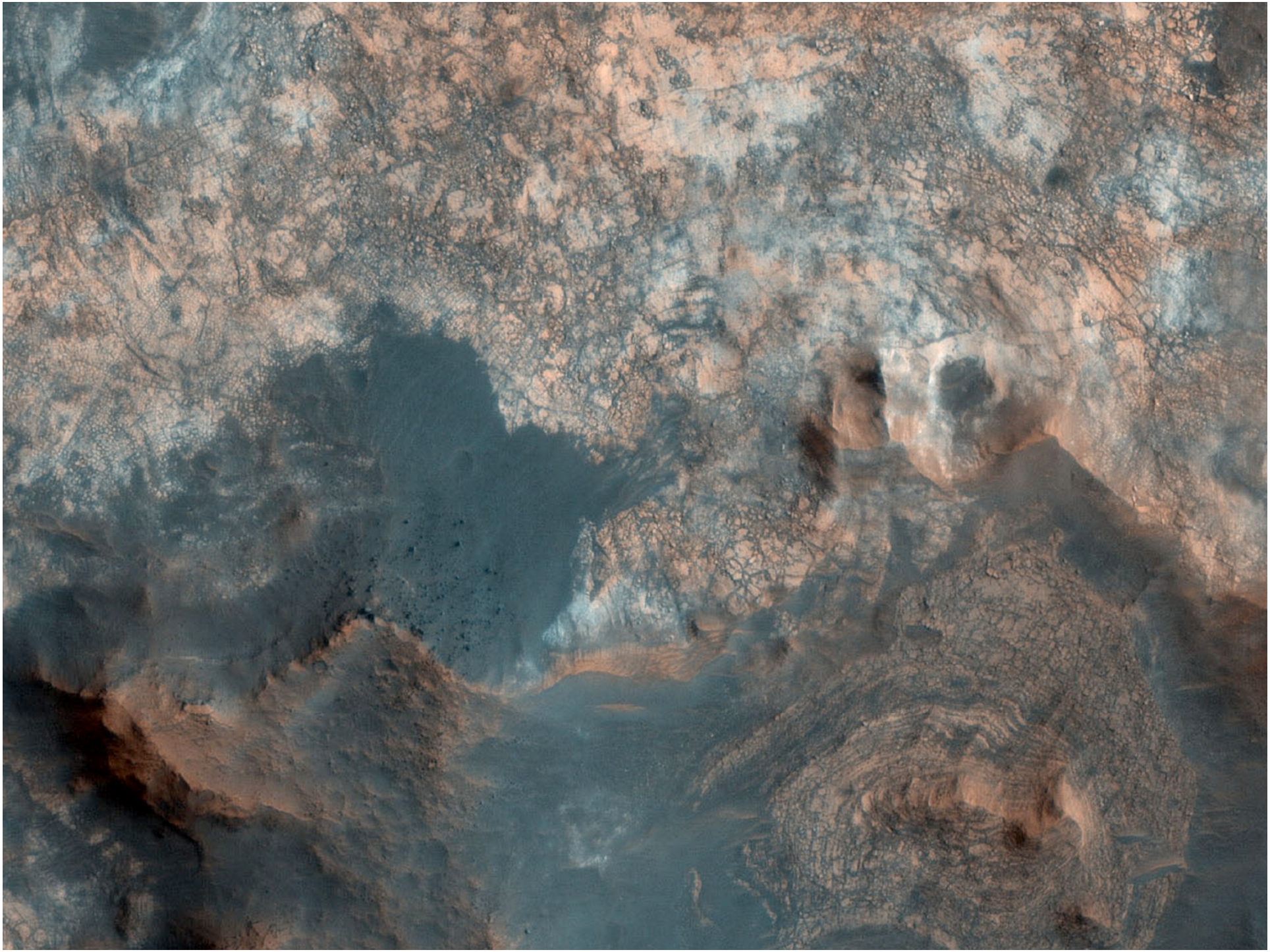


Mawrth Vallis

- *Exposure of stratified Noachian bedrock near the dichotomy boundary*
- *Cycles of deposition and erosion*
- *Strong signature of phyllosilicates from near-infrared spectroscopy*
- *Phyllo-bearing units are thick, flat-lying, and widespread*
- *Deposition occurred gradually, but very early in Mars' history*

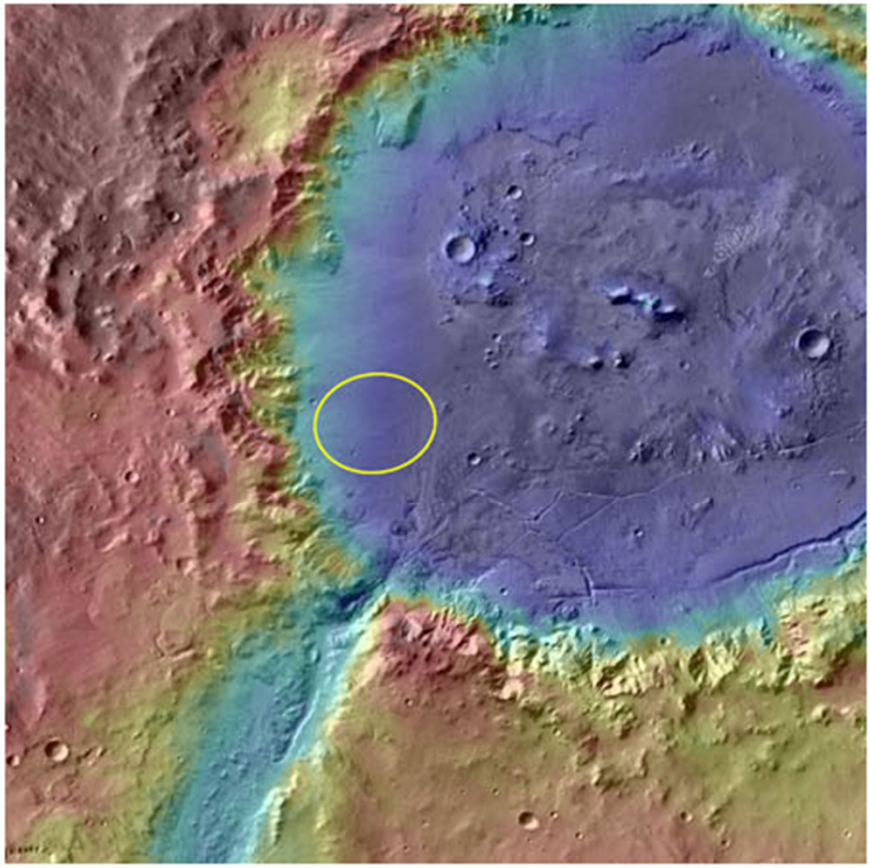






Holden Crater:

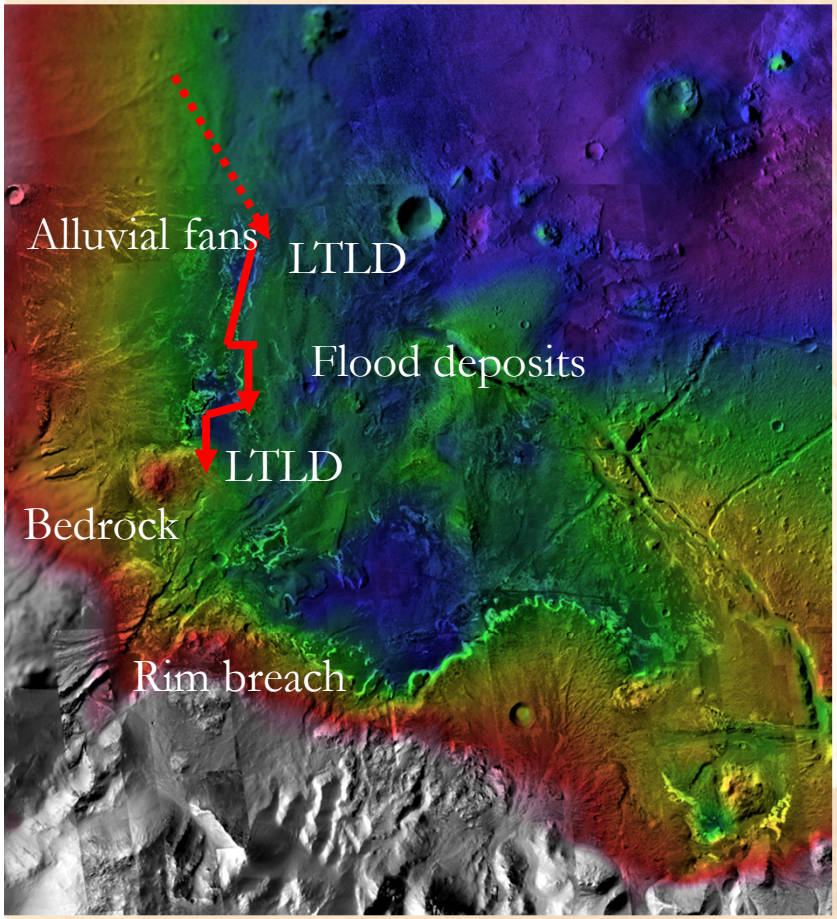
Paleolake and Flood Deposits along a Major Martian Drainage System

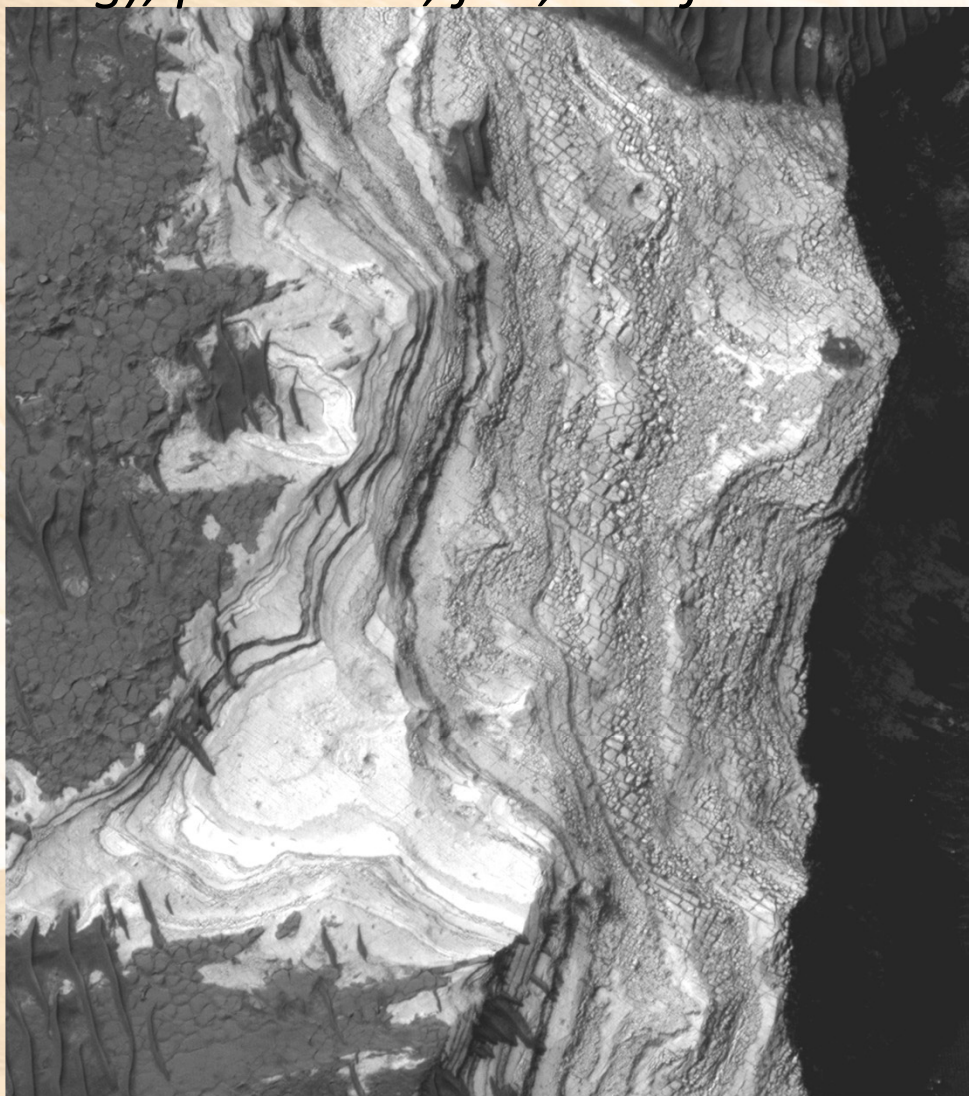


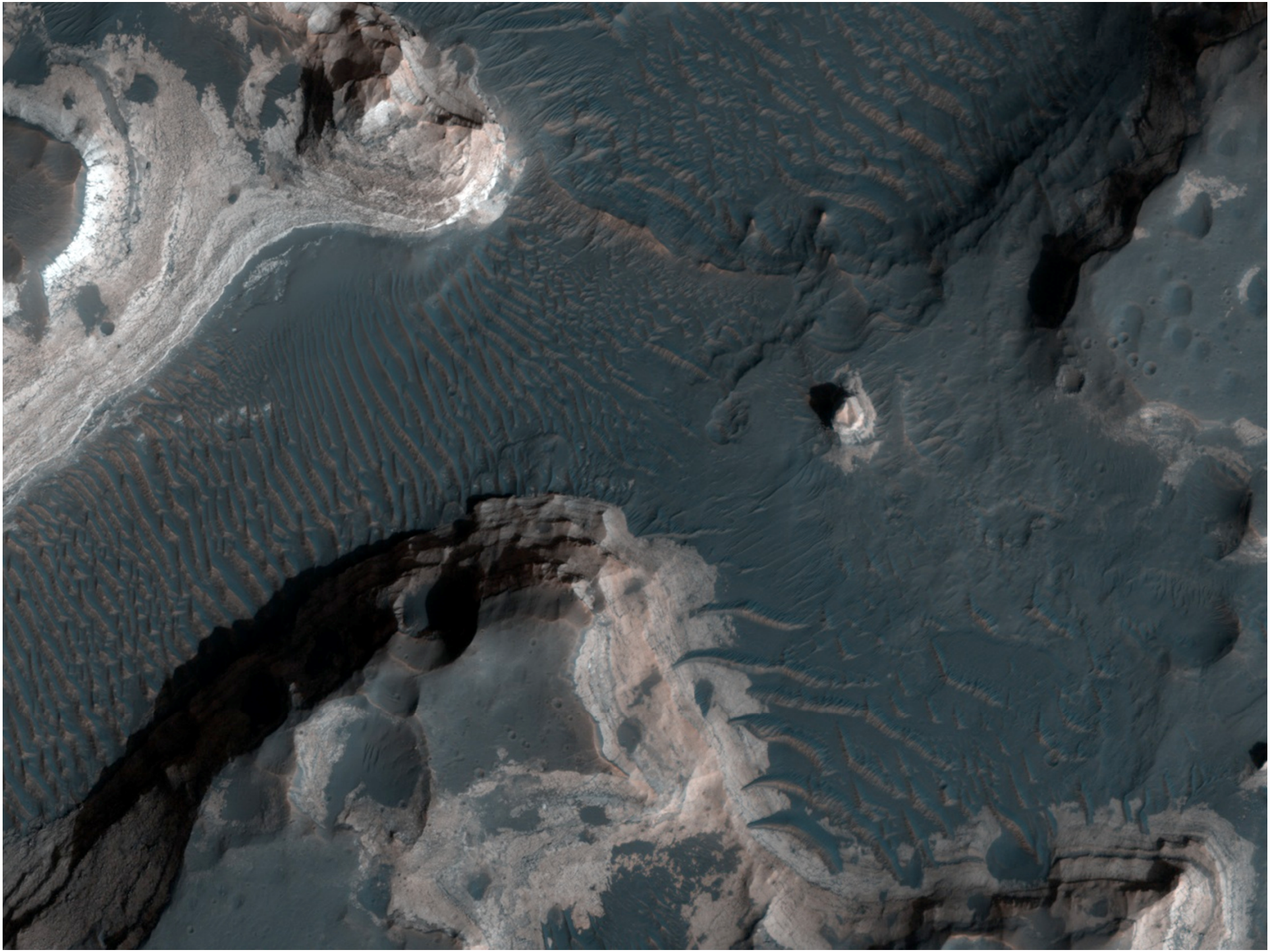
HOLDEN CRATER
(26S, 325E)

Holden Crater

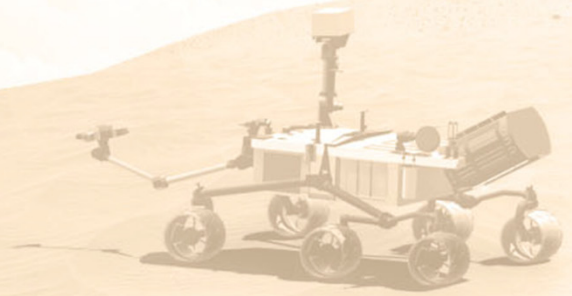
- *Offers opportunity to explore 80-m thick section of light-toned layered deposits (phyllosilicate-bearing), paleolake, fan, and flood deposits, and basal materials.*





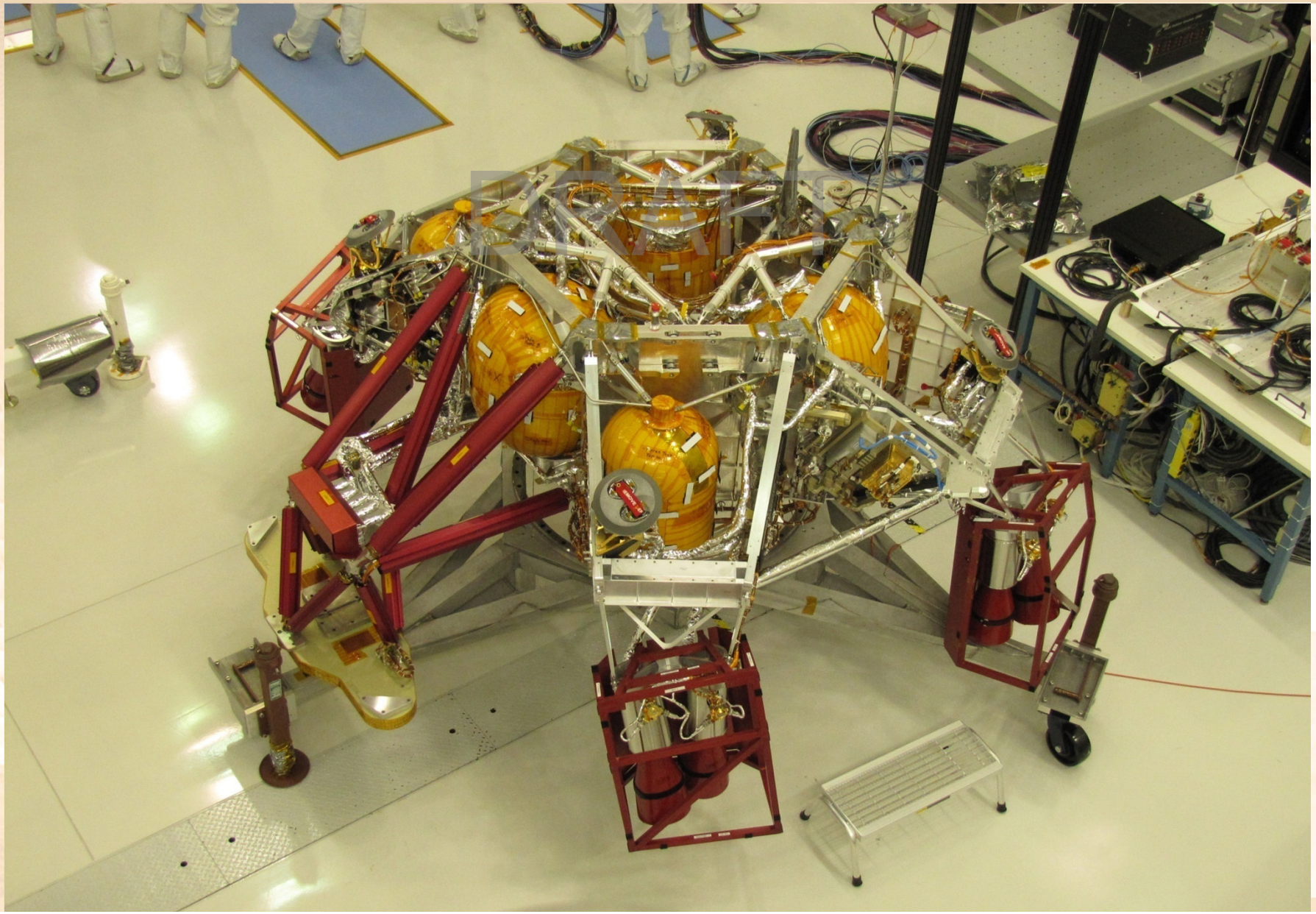


Rover and Spacecraft Pictures

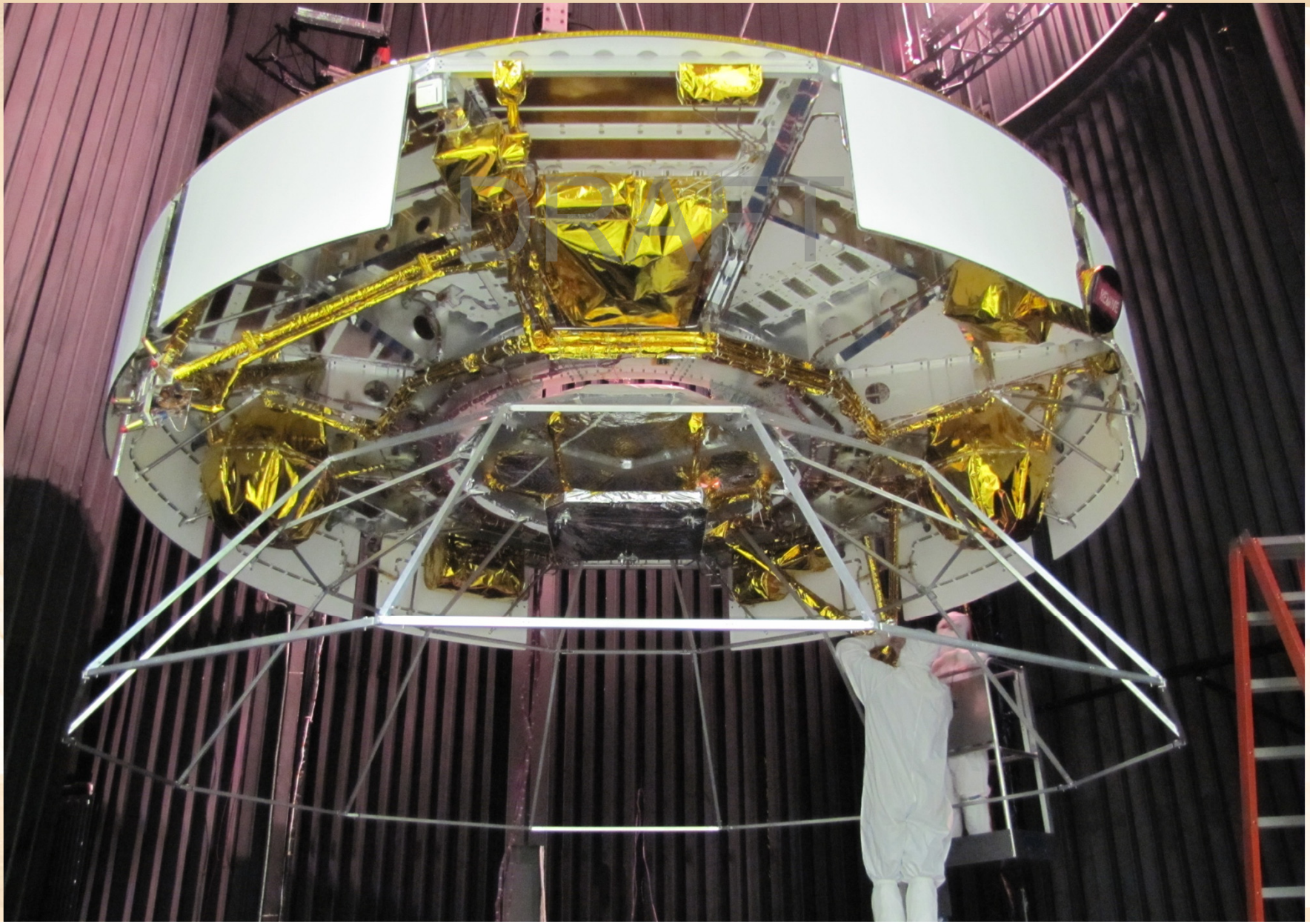


Rover Driving Test

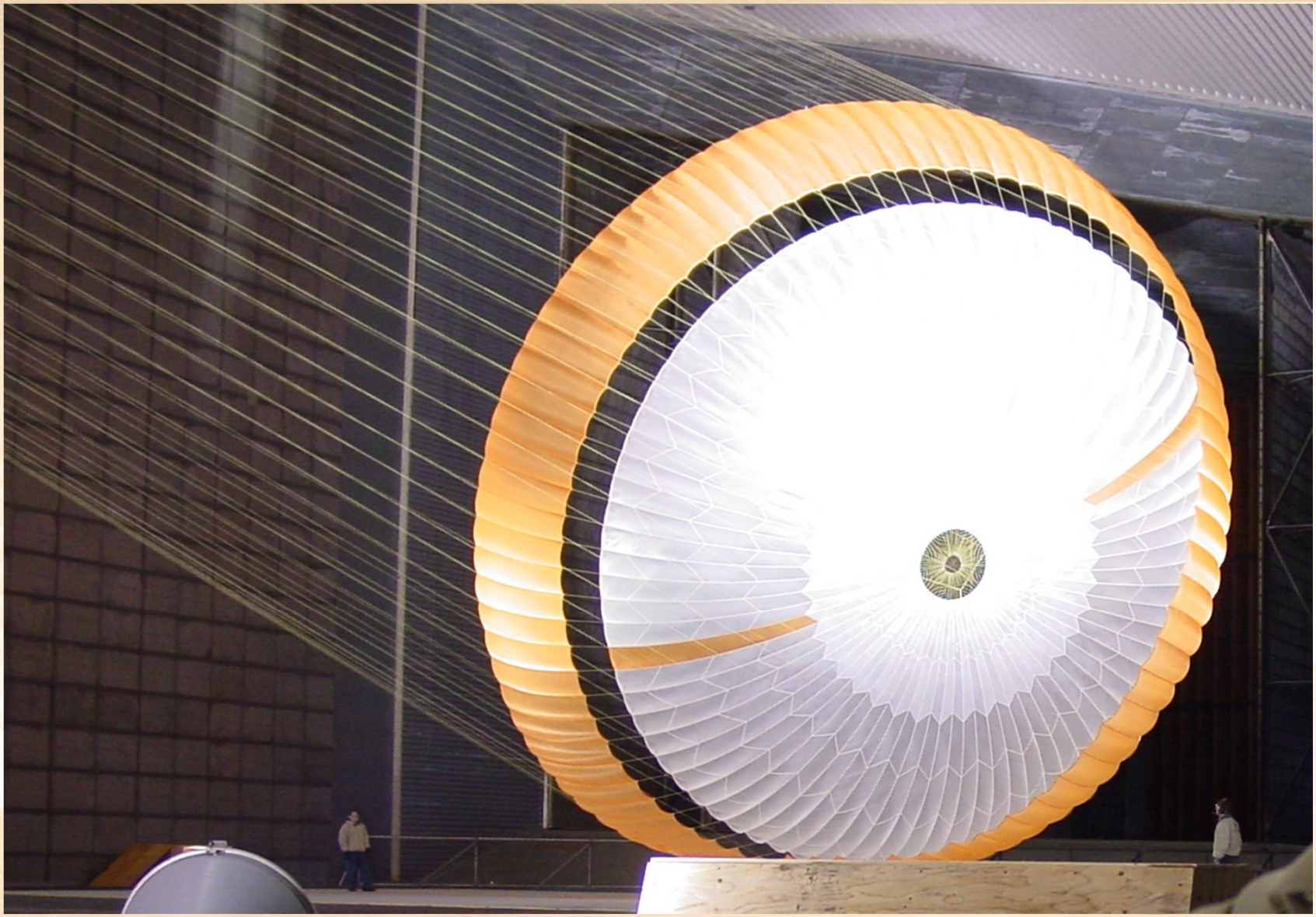
Descent Stage



Cruise Stage



Parachute Test



Assembled Spacecraft

Learn More about Curiosity

Mars Science Laboratory

http://mars.jpl.nasa.gov/msl

MSL for Scientists

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Mars Exploration Program

http://mars.jpl.nasa.gov

MSL Candidate Landing Sites

http://marsoweb.nas.nasa.gov/landingsites

http://webgis.wr.usgs.gov/msl

Mission Video

http://www.jpl.nasa.gov/video/index.cfm?id=979

Version: 2/17/2011

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